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Project Close Out Report
For: EVLA Construction

Date: May 8, 2013

PREPARED BY	ORGANIZATION	DATE
Chris Langley, Rick Perley, Gene Cole and others	NRAO NM Ops	May 8, 2013

APPROVALS (Name and Signature)	ORGANIZATION	DATE

RELEASED BY (Name and Signature)	ORGANIZATION	DATE

Change Record

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1 PROJECT CLOSE OUT REPORT PURPOSE

This Project Close Out Report is the final document produced by the Expanded Very Large Array (EVLA) construction project and is to be used by senior management to assess the success of the project, identify best practices for future projects, resolve any open issues, and formally close the project.

2 PROJECT CLOSE OUT REPORT GOALS

This Project Close Out Report is created to accomplish the following goals:

- Review and validate the milestones and success of the project.
- Confirm outstanding issues, risks, and recommendations.
- Outline tasks and activities required to close the project.
- Identify project highlights and best practices for future projects.

3 PROJECT CLOSE OUT REPORT SUMMARY

3.1 Project Background Overview

The goal of the Expanded Very Large Array (EVLA) Project is to improve most of the key observational capabilities of the Very Large Array (VLA) by at least an order of magnitude. Originally, the Project was divided into two Phases. The objective of Phase I was to improve the sensitivity, bandwidth, spectral resolution and frequency coverage of the existing 27 element array by the application of modern technologies. Funding was provided for Phase I. The objective of Phase II was to increase the angular resolution of the existing VLA by adding additional array elements around New Mexico. Phase II also included the addition of a condensed array configuration smaller than the existing D configuration and considered, but did not include, the addition of low frequency observing bands to the existing antennas. A proposal for Phase II was submitted to the National Science Foundation (NSF) in April 2004.The proposal was reviewed at the NSF in June 2005. In December 2005, the National Radio Astronomy Observatory (NRAO) was notified that the NSF was not able to support the proposal. This Project Close Out Report describes only the Phase I project.

The principal description of the science requirements, the technical specifications, the design selected to achieve the specifications, the schedule on which tasks were to be accomplished, and the task responsibilities are described in the EVLA Project Book along with the interface requirement specifications where one task interacts with another, either in the design or integration.

3.2 Project Highlights and Best Practices

Project Highlights:

- Leveraged existing VLA antennas and infrastructure to create state of the art array

  The astronomical community received a bargain in the $98M VLA expansion project. This price tag includes $59M in new NSF funds, $20M in contributed effort from NRAO, $17M from the Canadian partner DRAO (WIDAR correlator), and another $2M from Mexico. Building on the existing VLA site and antenna infrastructure, and using many existing and experienced staff, the EVLA has come in at a fraction of the cost required for a new facility of similar capability.

- VLA technical capabilities increased by at least an order of magnitude in every key observational area, with the exception of angular resolution

  The VLA's historical contributions to the astronomical community are well respected. Notwithstanding this, the instrument had begun to show its age and new technological developments employed by other observatories threatened to make the VLA less relevant heading into the 21st century. The upgrade has enabled the VLA to maintain its leading role in the field of centimeter astronomy.

Best Practices:

- International collaboration between Canada, Mexico, and the United States

  The EVLA construction project was administered by the NRAO under the purview of the NSF and Associated Universities, Incorporated (AUI). Collaborating with NRAO included the Dominion Radio Astrophysical Observatory (DRAO) National Research Council of Canada Herzberg Institute of Astrophysics (NRC-HIA) and the National Autonomous University of Mexico (UNAM). The economic relief realized by sharing the burden between Canada, Mexico, and the United States brings its obvious advantage. In all likelihood, future projects of this magnitude and greater will require international participation in order to become a reality. Also of great advantage is the intellectual exchange which comes with collaborative efforts across borders.

- Regular internal and external reviews

  Project development was greatly assisted by the practice of routine peer design reviews along with preliminary and critical design reviews for the major subsystems. Additionally, external advisory panels were regularly convened to assess progress. The first of these external boards was the EVLA Advisory Panel (EAP). As concerns shifted away from engineering and more towards science, the NRAO Director formed the Science Advisory Group for EVLA (SAGE) and later, the Panel to Advise on Science and EVLA Operations (PASEO). Additional reviews included the biennially held User's and Visitor's Committees. Towards the end of project construction, the NSF EVLA Path to Completion Review and the NRAO Director's Project Review were successfully conducted.

- Quality Assurance program

  Requirements verification, assembly and subsystem acceptance testing, inspection procedures and corrective action, along with consistent documentation standards were observed during development, production, and integration. These practices are carried over into operations.

- Incorporation of project management tools

  Work Breakdown Structure, resource loading, budget and schedule contingencies, risk register, Change Control Board, Earned Value metrics, and a clear reporting structure were all techniques used by management to guide and report on the progress of the project.

- System Requirements verification and acceptance testing

  EVLA Science conceived and conducted a series of rigorous on the sky tests to assure the scientific requirements and engineering specifications were met.

- The EVLA project was completed on time, on budget, and on specification.

3.3 Project Close Out Synopsis

Having met or exceeded nearly all project objectives and deliverables, the EVLA Construction project is now closed.

4 PROJECT METRICS PERFORMANCE

4.1 Goals and Objectives

The VLA was designed and built in the 1970s, utilizing the best technology of that time. Its wide bandwidth (100 MHz/polarization), multiple frequency bands (initially four, expanding to seven over 20 years), digital spectroscopic correlator (providing up to 512 spectral channels), and multiple configurations (providing range of over 50 in spatial resolution), were all unprecedented at the time, and were largely responsible for the continued pre-eminence of the VLA amongst all radio telescopes on earth.

Despite this continued success, there were good reasons to consider an upgrade of the VLA. Primary was that the goals of science evolve over time, as new discoveries are made with the new instruments at many wavebands. Centimeter-wavelength radio astronomy has a major role to play in these emerging fields, but can only do so if the major observational characteristics of its principal instruments improve. Fortunately, emerging new technologies enabled vast improvements in the sensitivity and flexibility of the VLA at a cost which is a small fraction of that for a new facility of comparable capabilities. Utilizing these new technologies, and building upon the established infrastructure in place, we proposed an expansion of the capabilities of the VLA by orders of magnitude in all areas except for spatial resolution.

The technical requirements for the EVLA were based on a comprehensive review of the potential science enabled by utilizing new technologies combined with the established infrastructure. There were four major science themes:

1) The Magnetic Universe: measuring the strength and topology of magnetic fields;

2) The Obscured Universe: enabling unbiased surveys and imaging of dust-shrouded objects that are obscured at other wavebands;

3) The Transient Universe: enabling rapid response to, and imaging of, rapidly evolving transient sources;

4) The Evolving Universe: tracking the formation and evolution of objects in our universe, ranging from stars to spiral galaxies and galactic nuclei.

For all, it was readily demonstrated that the improvements in VLA performance by implementation of modern technologies would result in spectacular new science by the world user community. The EVLA

Project was a comprehensive technical upgrade of the VLA - and a spectacular example of the advantages of a `leveraged investment'. The result of the Project is an efficiently operated `new array', which will provide astronomers a modern, general-purpose radio telescope capable of addressing the key scientific issues of today, and the yet-unforeseen issues of the future.

The primary technical requirements for the EVLA, based on the scientific requirements, and upon the availability of the necessary technology, were:

1) Continuous frequency coverage from 1 to 50 GHz in eight frequency bands, utilizing new or upgraded receivers at the Cassegrain focus;

2) A new wide bandwidth fiber-optical data transmission system, including associated LO and IF electronics, to carry signals with16 GHz total bandwidth from each antenna to the correlator;

3) New electronics to process eight signal channels of up to 2 GHz bandwidth each;

4) A new wide-bandwidth, full polarization correlator providing a minimum of 16348 spectral channels per baseline. The new correlator provides full polarization capability for four polarization pairs of input signals of up to 2 GHz bandwidth each;

5) A new real-time control system for the array, and new monitor and control software for the electronics system

6) New high-level software to provide ease of use of the VLA for its users.

Key performance goals for the upgraded array are given in Table 1.

Band	Center Freq. (GHz)	Frequency Span (GHz)	Maximum IF BW (GHz)	Aperture Efficiency	System Temperature (K)	SEFD (Jy)	1-σ Cont. Sensitivity - 1 hr (μJy)
L	1.5	1 – 2	2 x 1	0.45	26	325	6.3
S	3.0	2 – 4	2 x 2	0.62	29	235	2.9
C	6.0	4 – 8	2 x 4	0.60	31	245	1.9
X	10.0	8 – 12	2 x 4	0.56	34	300	2.3
Ku	15.0	12 – 18	2 x 6	0.54	39	385	1.7
K	22	18 – 26.5	2 x 8	0.51	54	650	3.5
Ka	33	26.5 – 40	2 x 8	0.39	45	760	4.1
Q	45	40 – 50	2 x 8	0.34	66	1220	6.5

Table 1: Key Performance goals

Measured performance is provided in Section 4.2. In some instances, it will be noted that measurements have yet to be taken to corroborate a particular specification. This is due to a lower priority assigned to some exercises, given that end to end performance of telescope operation has proven to be quite exceptional.

In addition to providing the improved scientific and technological capabilities, goals of the EVLA project included fostering international collaboration with our Canadian and Mexican partners, and completing construction on schedule, on budget, and with a minimal loss of observing time. The project succeeded in all of these goals.

4.2 Success Criteria Performance

The top-level goals described in Section 4.1 were translated into specific performance requirements for the Project. These are given in Section 2.2 of the EVLA Project Book. In the following, we present the achieved results, and compare these to the requirements, with explanatory comments when judged needed.

4.2.1 Antenna - Mechanical

4.2.1.1 Pointing

All requirements apply to observing under ideal conditions (low wind, clear skies, at night with antennas in thermal equilibrium with the environment). There are three sub-sections:

a) **Blind Pointing:** Using a recently-determined standard pointing model alone, the rms of the difference between commanded and actual pointing positions is to be less than 6 arcseconds for elevations between 30 and 70 degrees elevation.

Status: Post-fit residuals show this requirement is met for azimuth, but not in elevation. The left-hand panel in Figure 1 below shows the histogram of pointing results taken under ideal nighttime conditions. Azimuth residuals (top left) have an rms of about 6 arcseconds. Elevation residuals (bottom left) are about 8 arcseconds.

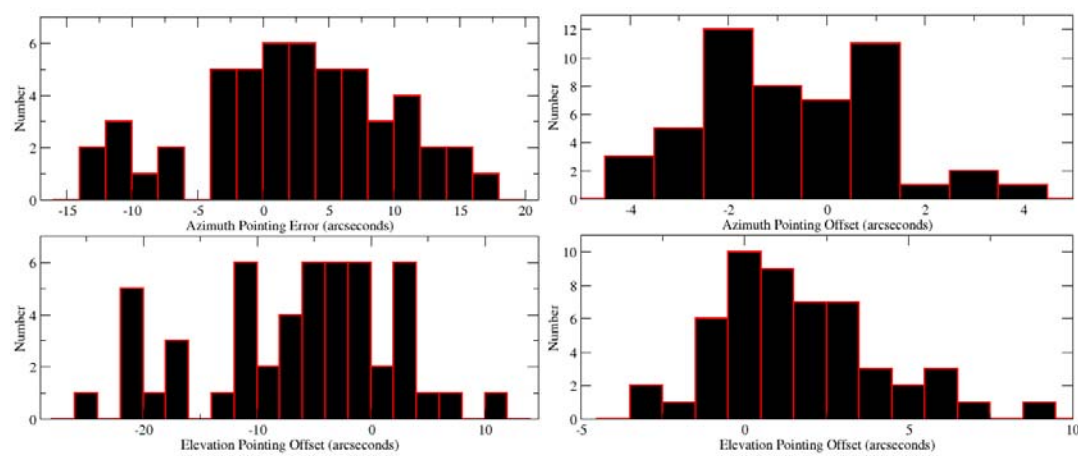


Figure 1: Pointing Results

b) **Referenced Pointing**: Transfer of locally-generated pointing offsets (defined as within 5 degrees in angle, and 15 minutes of time) for declinations between 20 and 70 degrees to be less than 3 arcseconds.

Status: Rms offsets of 3 to 4 arcseconds have been demonstrated for most antennas. The right-hand panel of the figure above shows the residual pointing error, following correction for the raw offsets. The offsets for azimuth (top) and elevation (bottom) are near 2 and 3 arcseconds, respectively.

c) **Super-Sidereal Tracking (OTF Imaging)**: Between 20 and 70 degrees elevation, antenna position errors are to be less than 4 arcseconds for drive rates up to 1 deg/min, and less than 8 arcseconds for drive rates between 1 and 2.5 deg/min.

Note: This item has always been regarded as a goal, rather than a requirement, as no budget for the necessary hardware changes was ever identified.

Status: Software tests for this capability have been successfully conducted, but no hardware tests have been conducted.

Comment: As described elsewhere in this document, it is necessary to replace the existing Antenna Control Units (ACUs). This will constitute a major change to our methodologies for determining and achieving accurate pointing. It is expected that the new design will improve our pointing. As the new design will not be implemented until later this year, no results are yet available.

4.2.1.2 Subreflector Positioning

Section 2.2.1.2 of the EVLA Project Book contains a lengthy list of requirements for subreflector focus and rotation accuracy. These requirements were taken from the original VLA requirements, which were themselves based on 23 GHz performance. As good overall performance at 48 GHz (Q-band) has been regularly demonstrated, no effort has been made to determine whether these requirements are met. A significant failure would be readily seen in the Q-band observing.

The same comment regarding the ACU replacement noted above (Sec. 4.2.1.1) applies here.

4.2.1.3 Antenna Slew and Settle Time

The time taken to move and settle between two positions separated by less than 30 arcminutes is to be less than 5 seconds. This requirement is based on enabling survey and holography observing. Figure 2 depicts the voltage amplitude provided by one antenna as it steps through a raster across a strong source. The step size is about 1/3 of the beam width. The step is made every 10 seconds, the integration time is 1 sec, and the dump rate is 1 Hz.

Status: Holography testing shows this requirement is met for elevation motions for all antennas, and in azimuth for most antennas.

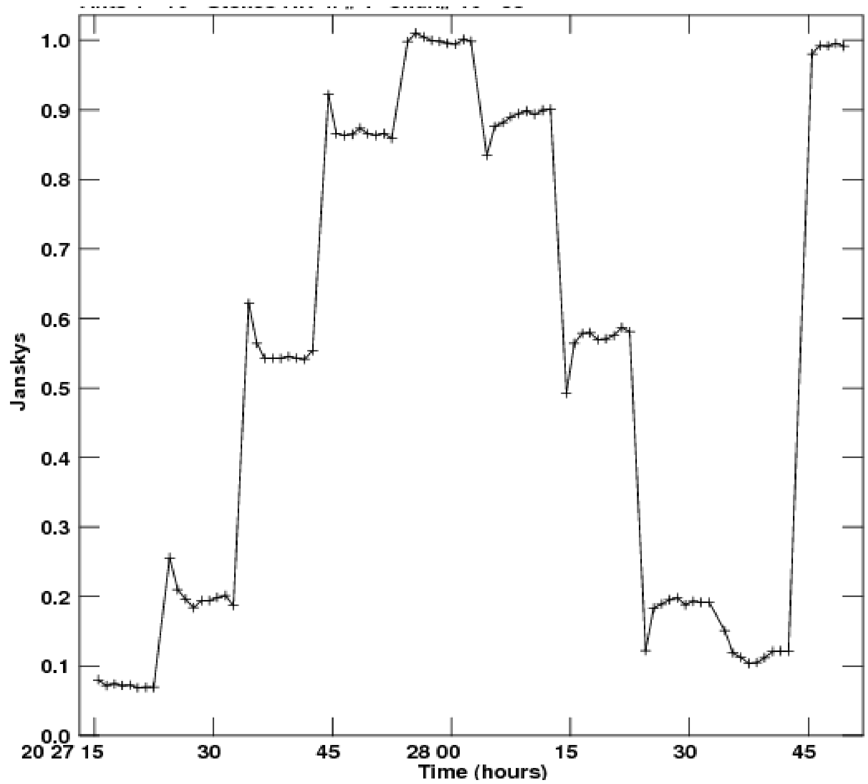


Figure 2: Antenna Slew Settling Time – 1 second integration per plotted point

The same comment regarding the ACU replacement noted above (Sec. 4.2.1.1) applies here.

4.2.1.4 Secondary Focus Feed Positioning

The positioning accuracy for the Cassegrain feeds is to be 10 arcminutes, and adjustable in the field.

Status: All receivers are mounted to permit accurate field alignment. The necessary holographic observations are planned for later this spring.

Comment: The effect of receiver misalignment is to produce a phase gradient across the antenna beam. Holography measurements to date indicate current alignments are sufficient for regular observing.

Antenna – Electrical

4.2.1.5 On-Axis Efficiency

We strive for high on-axis efficiencies across each observing band. The efficiency for each band is to meet the values given in Table 2.

Status: Included in the table are the results from ea24, the only antenna for which detailed measurements have been made.

Band	L	S	C	X	Ku	K	Ka	Q
Freq. Range	1 – 2	2 – 4	4 – 8	8 – 12	12 – 18	18 – 26.5	26.5 – 40	40 -- 50
Required Efficiency	0.45	0.62	0.60	0.56	0.54	0.51	0.39	0.34
Observed Efficiency	0.42– 0.5	0.55	0.58 – 0.65	0.58 – 0.65	0.56 – 0.63	0.48 – 0.56	0.35 – 0.50	0.26 – 0.37

Table 2: On-Axis Efficiency Specifications and Results

The results given in the table are from EVLA Memos 103, 109, 119, 125, 137, 152, and 165, plus unpublished results for S, X, and Ku bands.

Comment: Direct measurements of antenna efficiency and system temperature can only be done with `hot-cold' loads, an extremely labor-intensive activity. We have elected to do this for a single representative antenna. Astronomical measurements provide measures of the ratio 'Efficiency/System Temperature' which when combined with on-board system temperature measurements can provide a reasonable estimate of the antenna efficiencies for the remaining antennas.

4.2.1.6 Main-Beam Efficiency

No requirement was established for this item.

Comment: Main beam efficiency is a function of the aperture taper and antenna optics. The antenna efficiency is also dependent upon these factors – the two parameters are not independent. We decided to utilize the efficiency (which was easier to measure early in the project) as an indicator of antenna performance.

4.2.1.7 Feed Illumination

The feed illumination is to be within 5 cm of the antenna center.

Comment: This requirement is redundant with 4.2.1.4.

4.2.1.8 System Polarization Characteristics

Section 2.2.2.5 of the Requirements is written in terms of antenna polarization ellipse characteristics. Translated into the more familiar 'D' terms, the requirements are:

a) Antenna cross-polarization to be less than 5%.
b) Antenna cross-polarizations to be stable to 0.1% over an 8-hour period.

In addition, there is a requirement that the circular polarization offset (beam squint) remain constant to better than 6" over an 8 hour period.

Status: Polarization measurements have been reported in EVLA Memos 131, 134, 135, 141, and 151, for the L, S, C, X, and K band receivers. For all these, except C-band, the antenna cross-polarization meets project requirements except near the band edges. The C-band polarizers, which do not meet the requirements, are slated to be replaced by a new design expected to provide better than 5% cross-polarization. Stability at C and K bands is reported as better than 0.1 and 0.2%, respectively. The K-band results were noise-limited, and we have no reason to believe the stability at that band is worse than at C-band.

Specific observations at other bands have not been reported. However, scientific observations for which polarimetry has been done indicate performance at the required values. No measurements of beam squint stability have yet been made. However, this is set by the location of the offset feeds, which are fixed, and in any event affects only Stokes 'V' observations, which are rare.

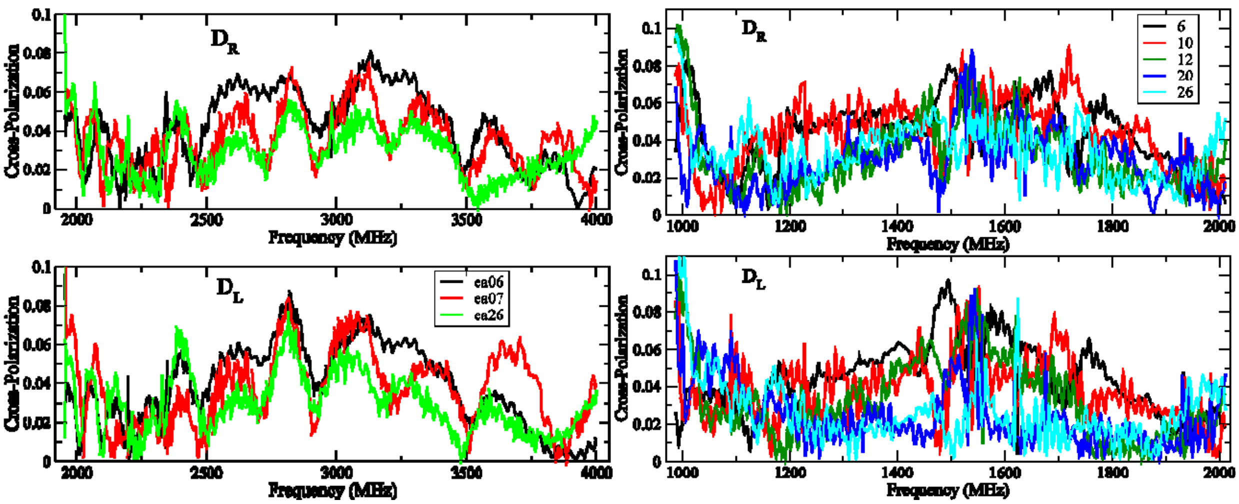


Figure 3: Polarization Results

4.2.1.9 Dichroic Capabilities

Dichroic operations are not part of the Project. The requirement here is only that the system design will not preclude future dichroic operations.

Status: The requirement has been met by arranging the Q, Ka, K and Ku band feeds on one side of the Cassegrain feed ring, and the C and X-band feeds (which would be paired with one of the others in a dichroic system) on the other side. Further, the LO system is designed to be able to operate at two frequencies, each in a different frequency band.

Receivers

4.2.1.10 System Temperature and Sensitivity

The system temperature requirements, and the typical mid-band measured values (except at Q-band, which are for the bottom end), are given in Table 3, in degrees Kelvin. A lower temperature results in a more efficient system. The requirements (and the observations) apply to clear, night-time, winter conditions.

Band	L	S	C	X	Ku	K	Ka	Q
Required	26	26	26	30	37	59	53	74
Observed	28 – 32	25 – 30	25 – 30	25 – 30	22 – 28	30 – 40	40 – 50	55 - 85

Table 3: System Temperature Requirements and Results

The most relevant parameter for observations is the Antenna Sensitivity, parameterized by the SEFD, defined (for a 25-meter antenna) as 5.62*Tsys/Efficiency. Low SEFD values are preferred. The requirements and latest measures are given in Table 4 for typical mid-band observing in good weather, except at Q-band, for which the values are for 41 GHz. Listed values are in Jy, and are the median values from all antennas.

Band	L	S	C	X	Ku	K	Ka	Q
Required	325	235	245	300	385	650	750	1220
Observed	342	246	274	237	212	402	561	1093

Table 4: Sensitivity Requirements and Results

Comment: The observations from which these results were derived were made utilizing the 8-bit samplers. The 3-bit (wideband) samplers cause a loss of about 15% in system sensitivity. As these samplers will only be used at the higher frequency bands (X-band and up), system sensitivity requirements are easily met. The C-band results pertain to the lower half of the band, for which a new 'thermal gap' assembly, to be outfitted in parallel with the new polarizers, is expected to improve sensitivity by ~10%. The upper half of C-band currently meets sensitivity requirements.

4.2.1.11 Linearity of Power Gain Measurement to System Power Variations

There are three requirements listed. Because of a change in operational methods, the requirements listed below are reworded to reflect the modern systems. The basic requirement – to be able to transfer system gain amongst sources with less than 0.5% error, over a range of input powers of a factor of 30 – remains unchanged.

a) Antenna electronics gain changes to remain linear to within 0.5% accuracy over an input power change of up to 15 dB (factor of 30). Any system gain changes of up to 15 dB to be monitored with the same accuracy over that same power range.

   Status: We have not met this requirement yet, by a factor of a few. This issue is being actively pursued at this time.

   Comment: The non-linearity is notable only for observations of the strongest sources. For observations of all 'normal' sources (up to ~ 50 Jy), gain stability and calibration accuracy of 0.5% is assured. Note that this requirement applies to the electronics. It does not apply to accuracy of antenna pointing.

   The following plot (Figure 4) shows the antenna gains over a 25 hour period, utilizing four standard calibrator sources. No trends have been removed. The scatter for each observation is from noise. The typical deviations from unity are less than 1%.

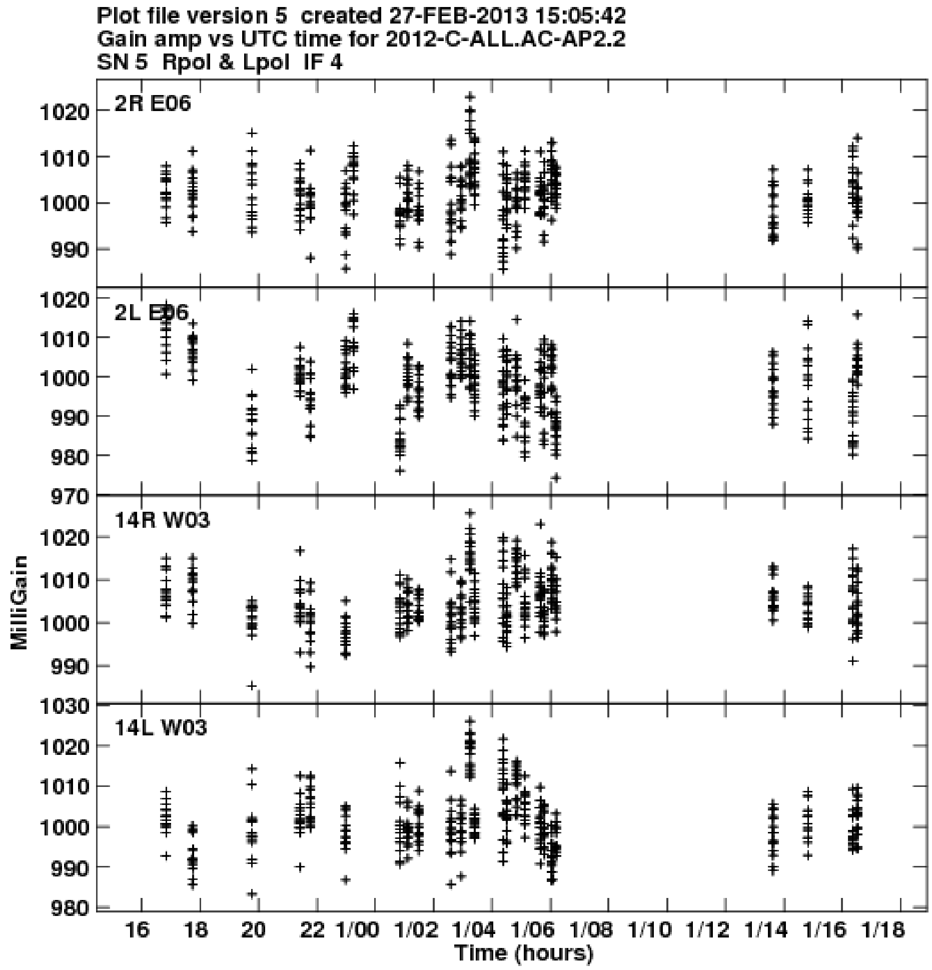


Figure 4: Gain Amplification Vs. Time

b) System gain stability and measurement accuracy to be accurate to 2% for power increments between 15 and 50 dB above cold sky.

Status: No specific measurements have yet been made. This requirement affects only solar observing.

c) Headroom requirements for the front ends, to 1 dB compression from cold sky, are 47, 48, 43, 42, 40, 33, 35, and 27 dB for the L, S, C, S, Ku, K, Ka, and Q bands, respectively. For the IF system, the headroom requirement is 32 dB to 1 dB compression.

Status: The receivers and IF electronics were designed to this level, but no specific test results are available.

Note: The requirements given here correct an error in the EVLA Project Book. The headroom requirements for the receivers were mistakenly written as headroom requirements for the entire electronics chain.

4.2.1.12 Temporal Phase Stability

All requirements presume round-trip phase corrections have been made. The requirements refer to electronics phase stability, and do not include changes due to atmospheric or system geometry errors. Note than a 1 ps time error results in a 17 degree phase error in at 50 GHz.

a) Rms phase jitter within a 1-second interval to be less than 0.5 fs.

b) Phase changes within a 30 minute interval are to be less than 6 ps.

c) Peak-peak fluctuations of the phase about the slope in phase within a 30 minute interval are to be less than 1.4 ps.

d) Any phase change associated with antenna motion is to be less than
   a. 0.7 ps for arbitrary change in pointing direction,
   b. 0.07 ps for antenna pointing changes less than 10 degrees.

e) The R-L phase difference is to be less than 0.5 ps, for all timescales.

Note: Requirements (b), (c), and (d) are all set to meet the limits imposed by the best possible atmospheric conditions

Status:

a) This requirement is to prevent decorrelation loss. The electronics system is designed to meet this requirement. System sensitivities, on sky, meet those expected from antenna performance tests.

b) Tests under good weather in compact configurations show these two requirements are met.

c) Same comment as in b).

d) The best test here is in the determination of baselines, which requires rapid all-sky observations. The result shows that baseline accuracy is not limited by the system stability, but by atmospheric variations.

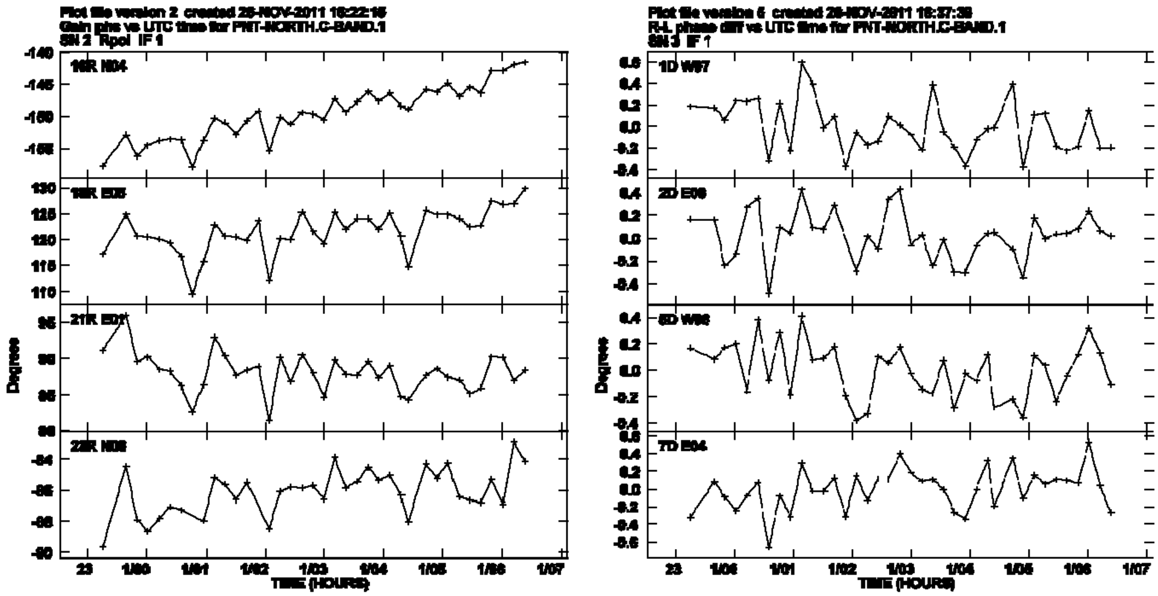


Figure 5: Antenna Phase Stability (L) and Difference (R) for C-Band

The left panel in Figure 5 shows antenna phase stability at C-band over an 8 hour period. Typical fluctuations are 2 degrees, corresponding to 1 ps time – well within requirements. The slope in the top plot is due to a baseline error. The right panel shows the (R-L) phase difference at C-band over an 8-hour period. The typical fluctuation is 0.2 degrees, corresponding to ~0.1 ps – well within requirements.

4.2.1.13 Bandpass Characteristics

The following two requirements refer to differential temporal changes. The requirements assume the gain variations associated with changes in amplifiers or attenuators have been corrected for. Atmospheric effects are not included.

a) Temporal Amplitude Stability: Variations in bandpass shape, in power units, are to be less than 1 part in 10000, on timescales of less than 1 hour, over frequency scales less than the band frequency/1000.

b) Temporal Phase Stability: Phase variations over frequency are to be less than 6 millidegrees, over timescales of less than 1 hour, and over frequency spans less than the band frequency/1000.

Status: The plot below (Figure 6) shows normalized differential bandpass amplitudes (the mean gain and bandpass shape are removed) over a two hour period for antenna 26 at 15 GHz. The fluctuations indicate the bandpass stability. The peak-peak range on these plots is 0.1%. The stability is close to the required level of 0.01%.

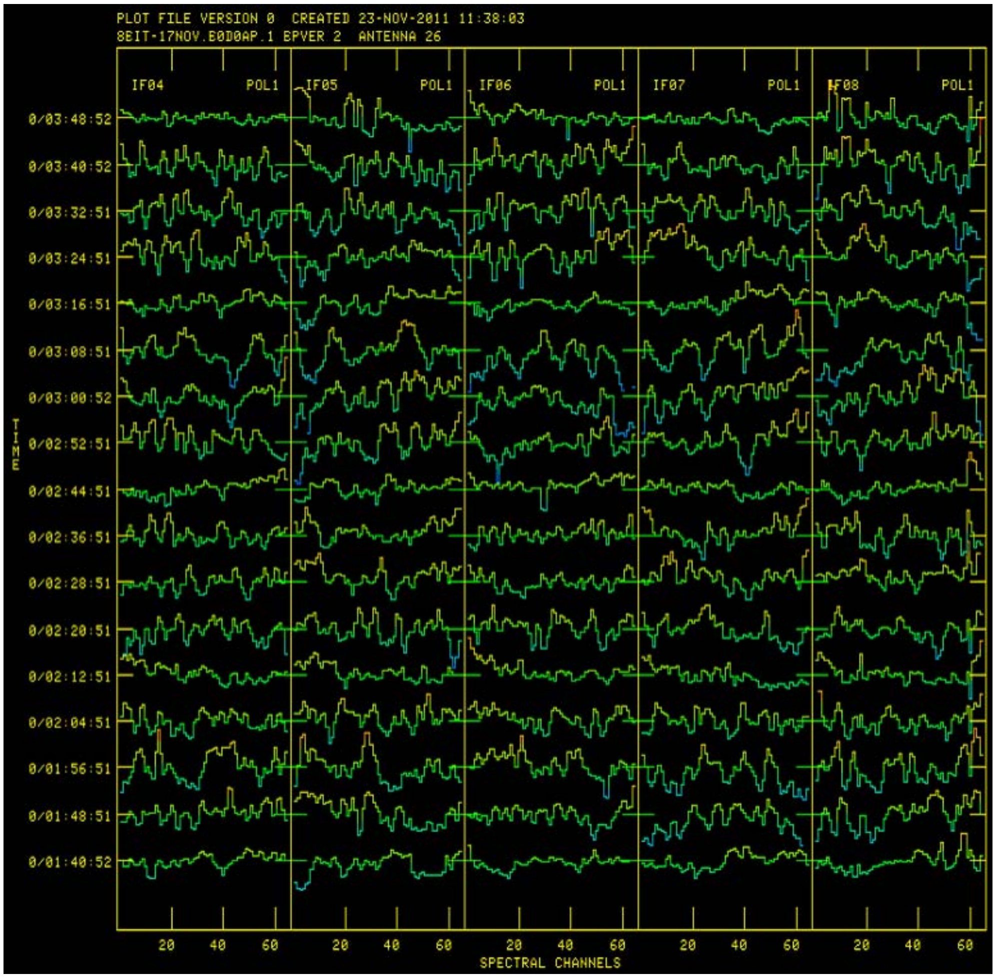


Figure 6: Bandpass Stability

The following requirements refer to the raw slope, in spectral power density or phase, of the bandpass defined by the electronics.

c) The spectral power density slope at the input to the 3-bit samplers is to be less than 1.5 dB/GHz.

d) The spectral power slope of the signals presented to either 3 or 8-bit samplers is to be less than (note: this corrects a typographical error in the EVLA Project Book):
   a. 12 dB/GHz at L-band
   b. 6 db/GHz at S-band
   c. 3 dB/GHz at C or X bands
   d. 1.5 dB/GHz at Ku, K, Ka, or Q bands.

e) Fluctuations ('ripples') is the spectral power density about the slope defined by the inner 1.8 GHz of the 2 GHz input to the 3-bit samplers are to be less than 4 dB, pk-pk.

f) Delay Errors (seen as a phase slope over frequency) are to be less than 2.8 nsec.

Status:

d) Figure 7 shows the raw spectrum covering 1.9 GHz using the 3-bit system at Ku-band. The power slope is less than 1 dB/GHz, well within system specifications.

e) The same plot shows the maximum fluctuations in spectral power are within 3 dB of the mean slope, easily within system specifications.

f) Easily met. The residual delay errors, following system calibration, are limited by atmospheric propagation effects - - much less than 0.1 nsec. Figure 9 shows the delay as a function of time over a 7 hour period.

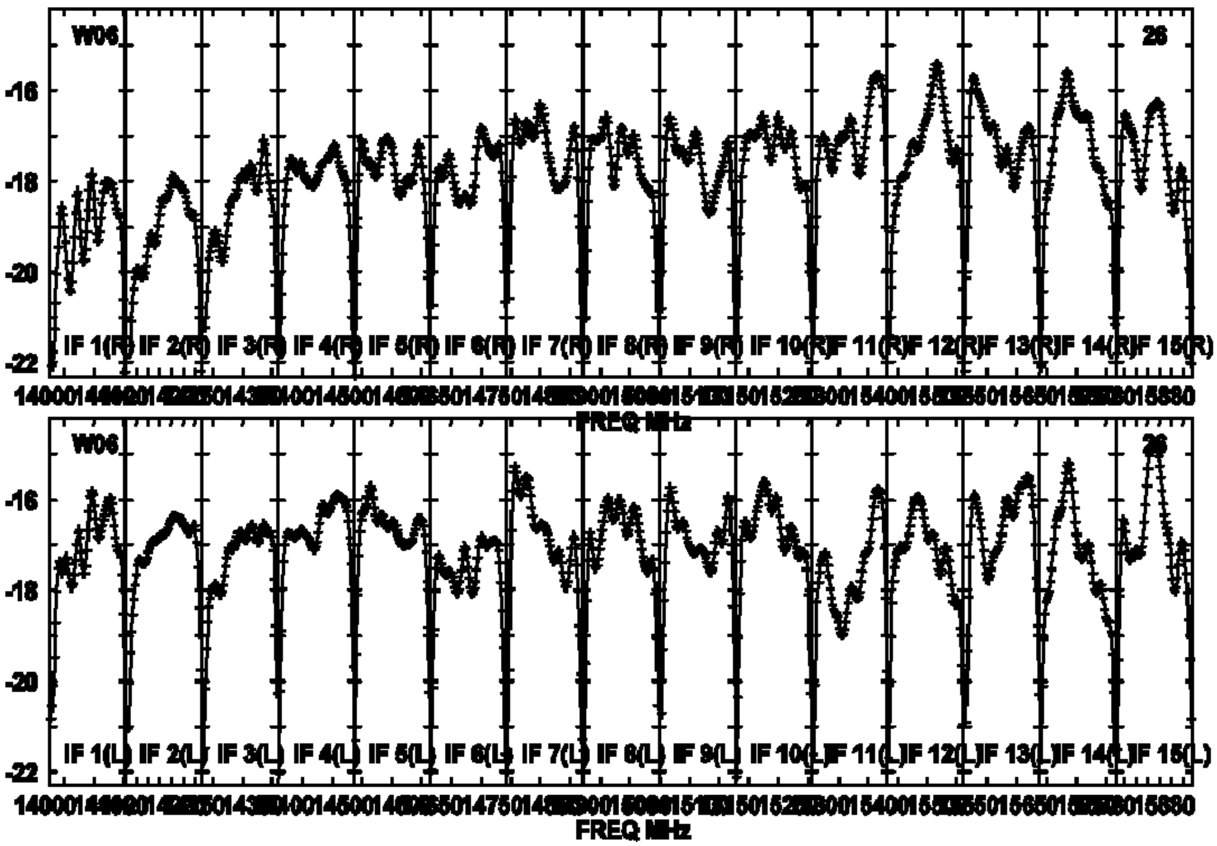


Figure 7: Power Slope < 1 dB/GHz

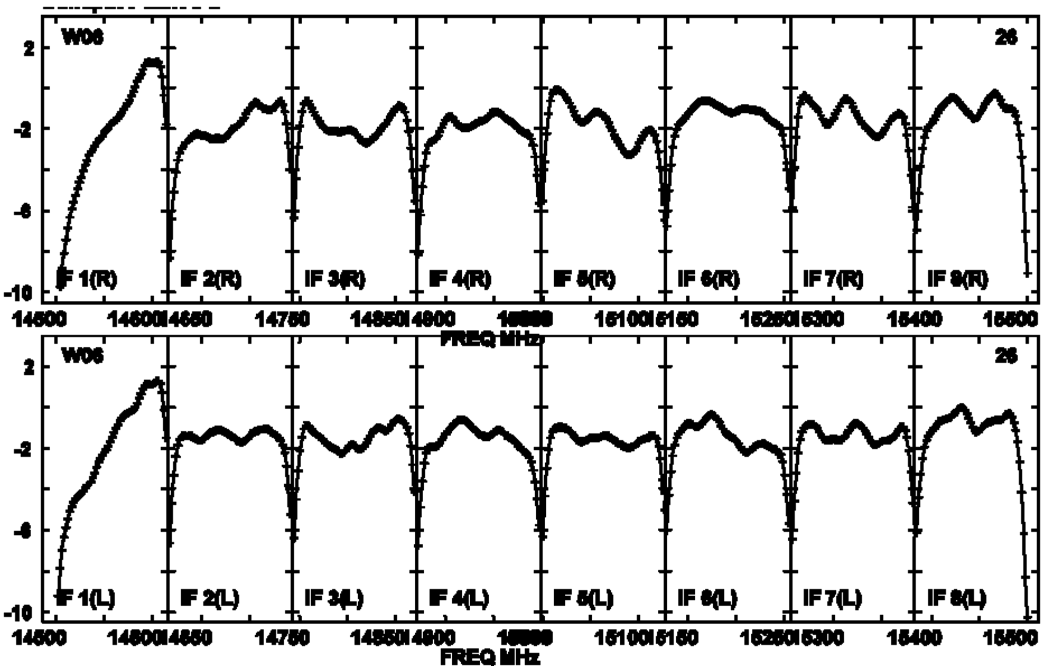


Figure 8: Maximum Spectral Power Fluctuations < 3 dB

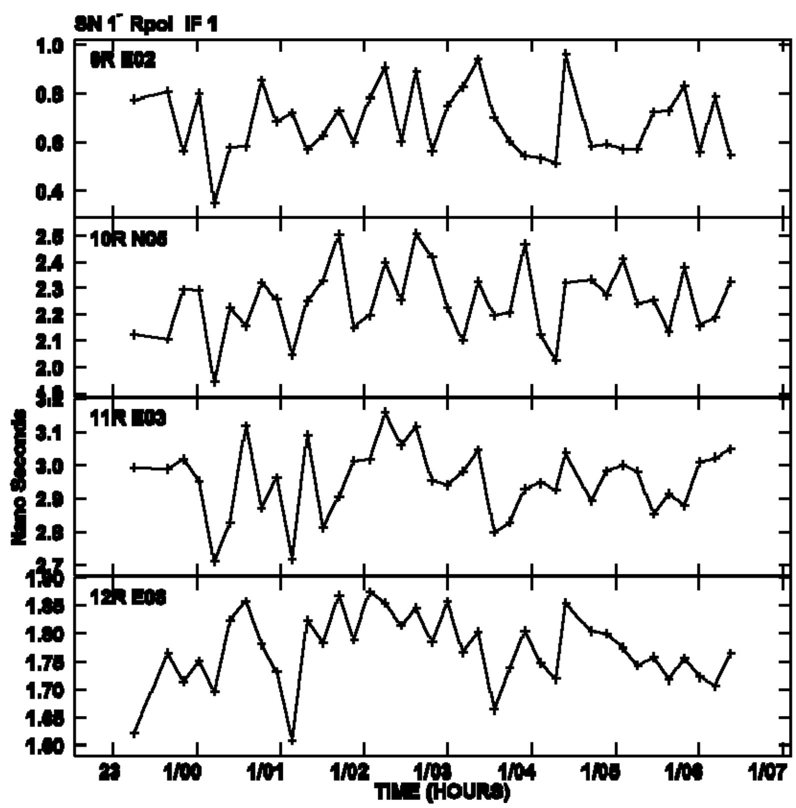


Figure 9: Residual Delay Errors < 0.1 ns

Required: System time must be accurate to 10 nsec.

Comment: Such accuracy is required only for pulsar timing.

User pressure for this capability has been very low, as the pulsar timing community has a strong preference for using single-dishes for this work. Hence, our limited resources have been directed to other areas of correlator development.

Status: The system is designed to enable this capability. No attempt to implement it has been made.

Correlator

The major requirements for the `WIDAR' correlator, as documented in the EVLA Project Book, are given below, with a status report for each.

a) The capability to process at least 27 antenna inputs, and be expandable to at least 48, in anticipation of Phase II of the project.

   Status: Up to 28 antennas are correlated on a regular basis. The ability to correlate up to 32 antennas is currently present. The correlator design would allow up to 48 antenna inputs.

b) Instantaneous bandwidth for each antenna input of up to 16 GHz, nominally organized as four oppositely polarized pairs of signals of 2 GHz each.

   Status: Fully implemented, and utilized on a regular basis.

c) Full polarization capability, with the user specifying which combinations are desired.

   Status: Fully implemented, and utilized on a regular basis.

d) At least 16384 spectral channels per baseline for all input bandwidths.

   Status: Fully implemented, and utilized on a regular basis.

e) The ability to 'target' up to 32 spectral transitions or narrow portions of the input bandwidth simultaneously, with velocity resolution of ~1 km/sec.

   Status: Fully implemented, and utilized on a regular basis.

f) The ability to avoid isolated strong RFI.

   Status: Fully implemented, and utilized on a regular basis.

g) At least 50 dB spectral dynamic range.

   Status: Final results are pending, though 40 dB of spectral dynamic range has been demonstrated.

h) A pulsar binning capability providing at least 2000 bins/baseline, with bin width 0.2 ms or less.

Status: This has not yet been demonstrated, as other correlator capabilities have higher priority. It is expected that the required development will be completed, and the capability demonstrated, within a few months.

i) A flexible subarraying capability, with at least 5 subarrays in cross-correlation modes.

Status: Full capability has been demonstrated in tests. In real science observing, three subarrays have been successfully administered.

j) A minimum data output integration time of no greater than 100 msec, with all spectral channels.

Status: This has been demonstrated by direct correlator observations. However, the data rate produced by this exceeds our current capability to write to the disk archive (external to the correlator). Significant additional resources would be needed to reach this goal. The current minimum integration time achieved is 10 msec, with 256 channels.

k) VLBI-ready, such that recorded data (either by tape or disk) can be correlated with at least the capability of the current VLBA correlator.

Status: This capability is accounted for in the correlator design, but it has not yet been demonstrated, as the VLBA now employs the DifX software correlator.

l) The ability to blank all correlations identified with potential RFI on an antenna input signal.

Status: This capability has not been demonstrated, as the external radio-frequency interference is not so severe to require the need at this time. Implementation of this capability is simply a matter of human resources.

4.2.6 RFI Management Plan

The EVLA Project Book Section 2.4 begins with a general description of the RFI environment and RFI issues, which we do not repeat here. The section concludes with a general description for four foundations – we provide a status report for each.

a) Measurement and Monitoring. We have on staff a full-time engineer, experienced in these matters, for this purpose.

b) Linear and Flexible Design. The receiver suite – including the digital portion – has been designed for maximum linearity. To date, we have no indication that RFI is degrading data quality outside of the correlator subband within which the RFI is found (see Section 4.2.5-g, above).

c) Suppression of man-made signals. This refers to internally generated signals by EVLA electronics and by emissions from other on-site equipment. Detailed testing for internally generated signals has been (and still is) conducted, and design modifications were implemented for those strong enough to affect array performance. There remain a few very weak and very narrow (spectrally) signals which are not expected to affect imaging performance. We will deal with these as staffing levels permit, should there be any indication of degraded performance.

d) Excision of affected data – both through simple flagging and through signal subtraction. The first of these is regularly implemented through new algorithms designed for the purpose. The second of these (which would permit preservation of the underlying astronomical information) is a subject of development world-wide, as strong RFI is a major factor degrading the data from the new generation of low-frequency arrays. No effort in this area has been expended by the NRAO, as the simpler 'flagging' route is sufficient for all users to date, and we have not the required human resources.

4.3 Milestone and Deliverables Performance

The project specified a list of major milestones that was used to measure progress and analyze overall dependencies and project impacts. The milestones were tied to key deliverables that the project had to meet in succession to advance forward. These milestones were used to measure critical path activities that were important to the ongoing success of the project by identifying areas of the project in need of improvement, and to forecast what deliverables would meet their targets so that the project could advance to the next stage. The milestones are listed as "Key Milestones" in Appendix 6.1 C.

The delivery of every major milestone has now been met and all deliverables have been accepted by NM Operations. Inevitably some deliverables were delayed along the way. Successful navigation through the myriad of electronics critical design reviews proved to be more of a challenge than anticipated. This resulted in delaying the start of electronics production and antenna retrofitting by 6 months. The project received an advancement of funding in 2004 which it used to accelerate purchases of large quantities of components. This helped return this portion of the schedule closer to its original baseline of progress.

The Observing in Transition Mode deliverable was two years later than expected due to the project's inability to recruit sufficient numbers of advanced software engineers during the first year of the project.

The delayed delivery of the prototype WIDAR correlator was in part due to finding suppliers that could provide high-speed processor chips that met specifications. The overall delay was 2 years. This delay had a domino effect and propagated through to several milestones that followed. These included the completion of the shielded room which would house the correlator, the start of Shared Risk Observing using the new system, and ultimately, the WIDAR correlator being declared operational.

Despite these schedule slips, all milestones were achieved with a high level of quality and earned customer acceptance by the planned-for end date of the project. No project milestones remain outstanding.

4.4 Schedule Performance

- Project Schedule Overview

The EVLA Project represented the 6th activity within the overall NRAO WBS. The Project was subdivided into the twelve principal Level 2 tasks shown in the Appendix 6.1 A. The detailed WBS task list, down to Level 4, is included in Appendix 6.2 A. Provided in this detailed WBS are the names of the engineers appointed within the Socorro Electronics, Engineering Services, and Computing Divisions that were responsible for the Level 2 tasks. Using Gantt methodology, every Level 4 task was broken down into measurable steps. These detailed schedules had milestones placed where appropriate to integrate the overall master project schedule together. The milestones from the Level 4 schedules were used to generate a Milestone Plan (Appendix 6.1 B) which was then used to track progress. A summary of the Milestone Plan was used as a report document. Periodic schedule updates provided the data used for earned value analyses (EVA) to generate the schedule performance index (SPI). The SPI in turn helped determine the percent ahead or behind schedule within reporting periods. These time metrics were collected, compiled and data validated as part of an ongoing process to review WBS status with the Level 2 engineers.

An example of a Level 4 schedule is shown in Appendix 6.1 D. The Project master schedule including details of all Level 4 schedules are kept in the EVLA Project online archive.

- Project Schedule Control Process

A dedicated scheduler was assigned at the onset of the construction project. This person had the responsibility of keeping track of the engineering activities which took place at the Science Operations Center and VLA in New Mexico, as well as the progress of component deliveries from NRAO's Green Bank (WV) and Central Development Lab (Charlottesville, VA) sites. On a daily basis, the scheduler kept track of all tasks, their dependencies, and the critical paths. Adherence to the project schedule was assisted greatly by key staff attendance at one or more regular meetings, each established with a specific purpose. These will be described later in this report.

Project schedule and budgetary status was routinely conveyed to NRAO upper management by established observatory reporting practices, and to the NSF by way of specified reporting guidelines. External annual or biennial reviews were conducted and progress reports were made available to the Users and Visitors committees, SAGE, and PASEO as part of the project review process.

- Project Schedule Corrective Actions

At the onset of the project the overall schedule baseline for completion was based on the NSF original 9-year funding profile. Shortly after the start of the project the NSF changed the original 9-year funding profile duration to 11 years. As a result the project schedule was modified to match the new profile.

A detailed review of the project schedule was carried out in December 2002 to determine the status of all EVLA WBS elements and their ability to start installation of the prototype system on a VLA antenna for testing in April 2003. It was considered important to start testing the new equipment on an actual antenna at the earliest possible time because it was only in the antenna environment that some problems, such as those caused by Radio Frequency Interference (RFI), would be identified. Some items, principally in the Local Oscillator, Intermediate Frequency, and Monitor & Control subsystems were found to be running late. These items were re-planned by prioritizing and phasing the activities so that essential equipment was available in time to allow for the outfitting of the Test Antenna per schedule.

In the area of Civil Construction, the burial of fiber optics (FO) cable along the array arms finished one full year ahead of schedule. The original intention was to retain some the FTE's used for burying the cable to work on the mechanical outfitting of the antennas when that activity commenced. By completing the task early, antenna outfitting was still a year away without a way to advance its start date. The project managed to keep some of the FO FTE's working in other areas, such as the construction of a cold storage facility. The cold storage building, which was cost shared with NM Operations, was placed under VLA warehouse inventory control and housed volumes of purchased quantities of electronics and mechanical hardware. Although the project lost some staff through attrition, it was able to retain the key individuals necessary to properly staff the antenna outfitting positions.

Early in the project the critical path was in the area of Monitor & Control, a situation that resulted from an inability to recruit software engineers of a sufficient level during the first year of the project. Once this recruitment was completed, the schedule had already suffered and time was required to recover.

During the middle years of the project two critical paths were identified at different times. The first major area of concern involved the completion of software tasks required to integrate the correlator with the EVLA Monitor & Control system. This was remedied when the project hired more software engineers to satisfy the level of work. Crisis averted, the next item warranting major attention involved the Front End subsystem. Design problems with the orthomode transducers (OMT) in some receivers, along with qualified staffing shortages, resulted in the projection of prolonged installation schedules. The new anticipated completion date of receiver installations was pushed out into 2013, which fell after the scheduled end of construction. Some good fortune was realized when the project recruited a particularly bright engineer to solve the design issues. His efforts paid dividends within a shorter period of time than anticipated, and the designs were completed and met specifications without issue. This resulted in a schedule which was brought back into line and the avoidance of completing project hardware after the 2012 due date.

- Project Schedule Integration with Managing Project

Retrofitting an instrument per a specified schedule while at the same time assuring it is available for scientific observations was a unique challenge for project management. A major mission of the EVLA project was to allow for continued VLA science observing throughout the duration of construction. Managing the project with minimal disruption through numerous hardware changes during equipment installations was paramount. It was recognized that any change in upper management personnel could have an adverse effect on VLA observing up-time in an attempt to meet scheduled hardware deliveries.

In December of 2004 an EVLA Deputy Project Manager was appointed in the person of Mark McKinnon. The position had previously been unfilled. As the project moved into its production phase particular emphasis was placed on budget and schedule aspects. A danger existed that these motivations would have an adverse effect on the philosophy to maintain optimal observing up-time at the VLA. In January of 2006, Peter Napier stepped down as EVLA Project Manager to take on a new role as an ALMA Systems Integration Engineer. Because he was replaced by Mark McKinnon the transition was very smooth and the VLA's goal of minimal disruption to the scientific community was achieved, while also maintaining a reasonable construction schedule.

4.5 Budget Performance

- Project Budget Overview

The detailed budget for the EVLA Project was produced using a bottom-up process in which a WBS Cost Data Sheet was completed by the responsible engineer for every Level 3 and Level 4 entry in the WBS. The Cost Data Sheet contained estimates of the personnel and materials and services requirements needed to accomplish the defined task over the duration of the EVLA project. The summary budget for the EVLA Project, obtained by rolling up all of the detailed Cost Data Sheets, is provided in Appendix 6.2 B. The detailed Budget costs for each of the Level 2 Tasks are kept in the EVLA Project online archive. An example of a completed EVLA Cost Data Sheet is included in Appendix 6.2 C. Note that all budget numbers in this document are in $k dollars.

- Project Budget Corrective Actions

EVLA neither received nor requested any additional funds during the life of the project. When changes to the budgetary baseline were enacted, a net zero sum gain in project finances was realized. The first change to the baseline definition occurred in 2001. At the request of the NSF the original 9-year funding profile duration was increased to 11 years in order to reduce the amount of new funds provided by the funding agency each year. To achieve cost savings and schedule compression, in 2004 $3.9M was advanced from the funding profile in order to accelerate the procurement of large quantities of production hardware and advance the completion of the retrofitting of the VLA antennas. The following year, a serious financial threat to hardware completion occurred. An estimated $3.1M of overrun in contributed effort was identified, a large portion which was the result of $1M in Data Management development being moved onto the EVLA budget. A call on project contingency was used to remedy the situation; however it was depleted in the process. To allow for a strong contingency, the Education and Public Outreach (EPO) element was de-scoped and its $500K in funds transferred into account reserves. EPO funding was placed in the project risk register as a work element to fund at a later date, if possible. $100k of project funds was returned to EPO later in the project.

Unanticipated distractions are not unusual during the life of a project. Two of these which particularly taxed project resources included, at different times, three "chart of account" changes and the transfer of project data for the implementation of a new observatory wide electronic time keeping system. These efforts were not expected at the onset of the project and produced extra work for the project office.

4.6 Metrics Performance Recommendations

At the onset of the EVLA Project, project management tool skillset levels varied amongst its team members. While this may be the case with any project, a project office needs have simple to use yet standardized metrics to help navigate the path through project implementation. These tools should include a fundamental use of Cost (EVA, CPI), Time (milestone tracking, SPI) and Risk metrics, all of which are invaluable tools for the management of a Project. Care should be taken to assure project team members understand the metrics which report on how they are progressing. Regular, timely, and accurate status reporting is imperative and is to be required. A data repository for the metrics, made available in an online directory specific for the project, is also needed. Modification privileges of this repository shall be limited to only a few to maintain data integrity.

Rather than purchasing costly commercial project metric tools, which often require contractual maintenance and support, and may also require a steep learning curve, the EVLA project made use of MS Office products. The low costs and general familiarity in their use by the project staff proved very efficient. The adoption and liberal utilization of MS Office products made it relatively easy to capture cost and schedule data for the EVLA Project and greatly assisted in the practices of reporting and documentation. It is recognized that other projects may require more specialized management tools.

It is highly recommended at the onset of any project that the adopted performance tools be explicated with all project team members. This helps provide clarity and guidance of the processes put to use to obtain progress status and helps to better monitor the project. Setting a clear expectation for progress and status reporting is another important step in keeping the project under control. Face-to-face contact with team members as often as needed is sufficient, but perhaps a better approach would be to require weekly written status reports. In some cases reports every two weeks may suffice, but a gap of more than two weeks before status reporting should never be allowed to pass, as too many activity altering events can happen during that time. When reporting status to management, managers should establish the requirements. If status is religiously reported from the team during the life of the project, and consistent methods are used, developing periodic overall status reports for the project should be very straightforward.

The use of these metrics is practical, but it is essential that staff possess adequate knowledge and experience in their implementation to assure successful reporting. One must also know how to analyze the results from these processes.

Earned Value management techniques were incorporated throughout the life of the EVLA construction project. The record of these may be perused in Appendix 6.1E.

5 PROJECT CLOSE OUT TASKS

5.1 Resource Management

Project resources remained very consistent during the course of construction. Because experienced VLA science, computing, and engineering staff were put into key project positions, expectations of the abilities of available personnel were understood. As such, little additional external expertise, either by way of additional staffing or outsourcing of a product, was required.

The transition of control and the transfer of resources by the EVLA management to NM Operations are complete. With the disbanding of the construction project team, all project deliverables are under the purview of NM Ops and are now being supported.

Turnover and acceptance activities included the transfer of knowledge, documentation transfer, and physical transfer of the product deliverables and test equipment. The EVLA is somewhat unique in that most of the local project construction staff adopted similar roles with NM Operations, enabling an overall smooth transition from construction to operations for personnel and equipment. In the case of the Canadian partner, several training exercises between DRAO and NRAO staff were conducted at each other's facilities in support of the correlator hardware and firmware. In addition, test equipment, spare components, and abundant support documentation for correlator assemblies were provided by DRAO to NRAO.

All product design and support documentation is in the process of being archived on the EVLA central server. Complete documentation for the WIDAR correlator has been provided to NRAO by DRAO. A complete listing of engineering documentation, EVLA Document A23010N0009, is maintained on the central server.

All records are stored following NRAO record retention guidelines. Design files are electronically stored for historical reference to facilitate later review. The project archive includes a description of the files being submitted, the application (including version) used to create the archived materials, and a point of contact.

In addition to engineering documentation, the following project data are archived:

- EVLA Project Book
- EVLA Project Plan
- Project management and oversight review records
- Status reports
- Configuration Change Board minutes
- Test Results (EVLA Memo Series)

5.2 Issue Management

Deliverables as defined in the EVLA Project Book have been completed. However, several follow on projects which arose as a result of the work to upgrade the VLA exist.

Components have been procured for the modification of receiver bands to enable enhanced solar observing. A plan is in place to complete the necessary retrofits before 2017.

During the construction phase of the project it became apparent that the three compressor units present on each antenna responsible for the cooling of Front End receivers would not be sufficient to adequately cool all eight wideband receivers. Provisions were made to install a fourth cryogenic system per antenna. A negative effect which resulted from the additional cooling requirements was a 190 Kw increase in power consumption and a per annum cost increase of $200k. Efforts are now underway to determine if more efficient cooling components are available or if the present cooling system design can be modified to be made more economical.

EVLA construction allowed for the upgrade of the antenna electronics responsible for astronomical data detection, transmission, and correlation, but the plan did not address the aging Antenna Control Units

(ACU) which are responsible for driving the motors which point the antennas. Towards the end of construction, ACU failures increased, and obtaining components for repairs became more and more problematic. Recognizing the gravity of the situation, and with the approval of the NSF, funding was set aside from project contingency in 2011 for a study to evaluate the current ACU, and to design and fabricate a complete prototype ACU unit in 2012-2013. The prototype unit is scheduled to be tested on an antenna during the summer of 2013. Funding was also obtained for two additional ACUs, to be fabricated immediately after the prototype unit is judged successful. The challenge remains to fund ACUs for the remaining 25 antennas (plus spares). However, components harvested from the three upgraded antennas will serve for a time to support those antennas which have yet to have their ACUs replaced.

The modifications to Front End receivers for solar observations, the effort to create a more efficient antenna cryogenic system, and the task of upgrading the antenna ACUs will be managed by NM Operations.

5.3 Risk Management

The EVLA Project's risk metrics was fully implemented in 2006. A risk analysis workshop was held in December 2006 to identify potential risks to the project and to develop any necessary risk mitigation procedures. A risk register was developed, and the risks were formally tracked on a quarterly basis to determine whether they could be retired or if corrective action was required. The Risk Methodology by which risks on the EVLA Project was measured along with the summary of the risk register is shown in Appendix 6.3. The Risk Register Summary will show that all risks identified with the EVLA project were retired prior to the close of construction. The complete risk register is kept in the EVLA Project online archive.

All risks identified with the EVLA project were retired prior to the close of construction. The complete risk register is located in the appendix.

5.4 Quality Management

Quality assurance and management methods were fully integrated into EVLA construction. While the majority of printed circuit board (PCB) assemblies were manufactured out of house, all prototype assemblies and production electronic modules were constructed in the Science Operations Center electronics lab in Socorro, NM. All of the equipment and tools required for assembly and test of EVLA assemblies and modules were installed in the electronics area. Assembly tools included reflow ovens, solder paste machines, Ball-Grid Array (BGA) machine, soldering stations, and microscopes. Test equipment purchased specifically for EVLA construction included X-Ray and BGA fiber optic examining stations, Communication Signal Analyzer (CSA), Digital Logic Analyzer, Optical and RF Spectrum Analyzers, and numerous other pieces of lab equipment.

All lab stations were modified to be Electro Static Discharge (ESD) resistant. Most or all of the integrated circuits used in the EVLA project are susceptible to ESD. These devices are most susceptible during assembly but are well protected once the modules are closed. Twelve ESD work stations were installed in the electronics area. Integrated into each of these work stations are conductive floor mats, ESD totes and parts bins, conductive bench top surfaces, and wrist straps. The building humidity was maintained at 40% to reduce static discharge. All electronics division employees were trained on ESD procedures and are required to wear ESD safety shoes. ESD smocks were also provided.

Figure 10: Typical ESD safe work station

Some modifications to laboratory practices were made during EVLA construction. Cellophane tape dispensers and Styrofoam coffee cups have the ability to generate large static charges. Tape dispensers were removed from the ESD work stations and the NRAO-provided Styrofoam coffee cups were replaced with paper coffee cups during the early days of project construction.

Circuit board production runs took place at out of house vendors. To confirm that all traces are correct per the design and without short or open circuits, all bare PCBs were subjected to an electrical test as part of the manufacturing QA process. After successful completion of this test, most or all of the components were installed by the external manufacturer. Standard practice was for delicate components such as BGAs or laser transponders to be installed by NRAO technicians after conducting a power test of the partially populated boards so as to not risk damage to the more expensive components. After each electronic assembly board was fully populated and tested in the electronics lab, module integration took place. Modules then underwent performance testing. For the purpose of module identification, to document module history, to confirm all required testing was performed before the module was installed in the array, and to log maintenance and repairs during the life of the module, a traveler document was assigned to each completed module.

Acceptance testing of EVLA electronics was performed on multiple levels. Initially modules were bench tested against the specifications for the particular unit. When the modules were installed in an antenna, a detailed subsystem acceptance test was performed, followed by a rigorous acceptance test of the larger system which was certified by the electronics division head or by the system engineer. This occurred on every antenna as it left the antenna assembly barn at the VLA. The results of each test are archived on the EVLA central server. This formal acceptance test verifies the functionality of every module and receiver and includes the existing Antenna Control Unit (not part of the upgrade project). Band-pass plots of cold sky were obtained using all system components. Upon successful completion, the antenna was then accepted into the array. A final systems level test which included actual pointing was run by Operations before each antenna was certified for observations.

The quality which goes into each EVLA module is enhanced by having the engineers and technicians who designed, built and tested the module also responsible for their maintenance during regular operations. Unlike some other projects where hardware is designed in one place, built and tested in another, and then delivered to yet another location, this continuity empowers the staff and instills in them a vested interest for maintenance control over the lifetime of the module. For example, if during the prototyping stage the technician discovered the power supply board too difficult to replace, the design would likely be changed. Well-designed and understood modules were the result, along with a pride of ownership for the technician.

5.5 Communication Management

Internal and external communication was achieved using a variety of methods. Verbal, email, video, and communication by way of database tracking were typical. Meetings targeted with a specific purpose followed-up by the dissemination of information via email and/or verbal methods proved to be indispensable. Status of project activities to the NRAO Director's office and in turn, to the NSF, was mostly conducted by way of formal quarterly and yearly reports and project plans.

Each division within the project conducted regular meetings, usually weekly, to review status, identify critical activities, and to adjust resources where needed. To allow for the unpredictable challenges which can suddenly have an adverse effect on plans, and to continue construction tasks with the greatest efficiency despite last minute hiccups, daily early morning meetings were conducted between the engineering construction groups in Socorro and those stationed at the VLA site. Monday morning Project Coordination meetings were held to give the various WBS leads the opportunity to report on progress, coordinate with other groups, and discuss issues which crossed boundaries. Also, once a week a videoconference was held between the DRAO correlator group and the NRAO correlator test scientists, computer scientists, and engineers to assure firmware and software updates were fully understood, and to plan for hardware deliveries and installation. These meetings also served as a platform for the transfer of knowledge. Another weekly meeting involving commissioning was established so that the responsible scientific staff would have a forum to provide status and to coordinate upcoming testing activities. Because the VLA remained operational throughout the construction project, a balance between construction activities, testing, observing, and commissioning had to be maintained. Twice a week, on Mondays and Fridays, a committee consisting of the New Mexico Assistant Director, the EVLA Project Manager, and the Science, Computing, Commissioning, and Correlator Test Leads attended a Priority Management meeting to set and adjust work schedules and to determine which activities warranted the most attention. All of these meetings contributed to the clear communication necessary to maintain steady progress on the construction project while also keeping the VLA available to the astronomical community.

Two adjustments to the meeting schedule was made during the final two years of the project. The Monday Project Coordination meetings would occasionally get bogged down in engineering details which were more suited to a different forum. To offer relief, the project manager introduced weekly

Engineering Task Level II (WBS) meetings to assess the status of lower level engineering challenges, assign priorities, and to divert resources where appropriate. As the project approached completion, additional attention was directed at the task of retiring risks. Regular meetings were held to allow the Project Manager, Scientist, Systems Engineer, and Computing Division Head to discuss outstanding issues and formulate strategies for solving them. Depending on the topic, other staff from the project would be invited to attend these meetings, which were held approximately every other week.

The typical daily communication within the project was multi-directional: Up and down vertically along the org chart and across boundaries when one product group or computing group required direct contact with another. Based on discussions with the project leads and NM Operations administration, the usual practice would be for the Project Manager to assign or adjust the activities of the engineering staff via the Computing, Electronics, or Engineering Division Leads. In turn, feedback from computer scientists, engineers, and technicians to their Leads, or to the Project Scheduler, would be provided to the Project Manager, who would either adjust activities accordingly, or when needed, bring issues to the Priority Management meetings.

In general, communication across and within the EVLA construction project was highly efficient. This is certainly true for dealings within New Mexico operations by virtue of the close proximity of the key project personnel. Communication between the management and rank and file at the different NRAO sites (Charlottesville, VA and Green Bank WVA) was also quite solid. Between NRAO and DRAO (Penticton, Canada), communication was very good. Regular weekly meetings between the two sites, frequent visits by Penticton staff to Socorro, and the friendly nature of the two organizations greatly contributed to this.

Very few changes in the way information was shared and discussion was carried out were made over the course of the project. Usually, this involved changes in reporting styles dictated by NRAO upper management or the NSF. At one point, the project manager did feel the need to get directly involved and establish weekly Level II task meetings to assure proper attention was given and priorities assigned to the subtasks which fed into the ultimate goal of delivering EVLA compliant hardware per schedule. In another project, these project meetings likely would not have to be administered directly by the project manager. During EVLA, given the mandate to maintain observing while juggling hardware and software upgrades, testing, and commissioning, the project manager felt the need to assert himself in this area.

5.6 Customer Expectation Management

With the exception of the reassignment of EPO funds discussed in Section 4.5, the EVLA project never sacrificed its original goal to improve the key observational capabilities of the VLA by at least an order of magnitude. Customer expectations remained consistent throughout the life of the project.

5.7 Asset Management

Project assets, whether they are instrumentation or other equipment, offices and laboratory space, or regular operations staff, were transferred from the construction project to VLA operations in the time leading up to and at the close of construction.

Also transferred from EVLA purview to other projects was a considerable amount of unspent capital. During the final year of construction, with the resolving of the last few project risks, it became apparent that some leftover project funds would be available. NRAO submitted to the NSF their recommendations for the wisest use of these funds, which totaled approximately $689k. These recommendations include the aforementioned 2 ACU units, electrical and building improvements at the VLA site, additional support staff for FE receiver solar mode retrofits, and funds for additional data archive hardware. These are described in the document Remaining EVLA Project Funds Management Plan, which is located in Appendix 6.4. The NSF agreed with the recommendations and granted permission to redistribute the funds per the *plan*. With the closing of the construction project WBS accounts, all remaining funds were transferred to new accounts to fund VLA projects in ACU development, electrical infrastructure, buildings, additional computing equipment, and to accelerate solar mode retrofits for various receiver bands. All these projects are administered under the purview of the Assistant Director for NM Operations.

5.8 Lessons Learned

Over the ten-plus year span spent on EVLA construction, and with a considerable portions of ALMA project construction taking place in the same proximity, EVLA personnel were in a good position to experience which practices worked well during construction and which would benefit from improvement. These findings, or lessons learned, are compiled in Appendix 6.5. A few of the notable lessons are described here.

An overwhelming sentiment was that the close proximity to each other of the majority of the construction staff contributed to excellent and efficient communication. Project construction took place in two primary locations, New Mexico and Penticton, with some components supplied from NRAO staff in Green Bank, WV and Charlottesville, VA. This not only facilitated regular face to face meetings between staff working on the same subsystem, but also allowed for impromptu discussions where paths forward could be decided in as little as ten minutes. Furthermore, the close proximity between the development labs in Socorro, NM and the VLA made for convenient equipment installation and on the sky testing. In contrast, hardware development for the ALMA project took place in many locations around the world. The difference between the two projects was readily apparent. Whereas major design or policy decisions for EVLA may take an afternoon to a week or two, the perception was that similar decision making processes in ALMA could be drawn out over weeks or even months. A further benefit of having the project spread over fewer, established locations was that by nature of the construction teams being at astronomical observatories, a high number of the scientific, computing, and engineering staff was already experienced in the field of radio astronomy.

The EVLA project proved to be a resounding success. However, if given the opportunity to produce another radio telescope array, some modifications to how activities were carried out were discussed. Because the VLA was in close proximity to the construction of electronic assemblies in Socorro, an end to end laboratory system test fixture, while desirable, was not considered mandatory early on in the project and therefore was not funded. Views have evolved regarding this. Early during system integration it became apparent that modules which perform flawlessly in a lab environment rarely reproduce the same results on an actual telescope. Reasons for this are numerous. Slight nuances in signal integrity or timing, inconsistent grounding methods, power cleanliness, general environmental conditions, noise, and the overall interactions of a piece of hardware when placed in an entire system are but a few items which could result in the malfunction of a piece of electronic equipment. On the initial antennas, and even during later integration, much time was lost due to malfunctions during and after the electronics was installed on an antenna. A complete system test facility – including a platform for software and a test correlator - coupled with rigorous system level acceptance tests, will not assure every piece of hardware leaving the lab would perform as expected once in the array, but it would certainly increase the success rate. Conversely, motivated by the physical distance between Socorro and the ALMA Operations Support Facility in Chile, the ALMA Back End group developed a system test set for their electronics. That test system was limited to a “pseudo” Front End which simulated broadband noise and a “pseudo” correlator which captured IF data bit patterns and performed manipulations via LabVIEW. While not optimal, making use of this limited test system resulted in the Back End deliveries arriving in Chile in a reasonably functional state. In short – while having the array in relative close proximity to the development lab was a tremendous advantage, having a full integration test facility present in the lab would result in much greater efficiency.

Two items regarding staff organization and overall staffing resonated with the project team. For several years the idea of organizing a dedicated group of individuals to assure the proper integration and testing of hardware along with a consistent application of system directives was discussed. Differing views as to the wisdom of establishing a dedicated group of systems oriented engineers and technicians persisted throughout construction. A systems group was not budgeted during project planning. Additionally, only one slot for a dedicated Systems Engineer was included in the original project plan. The philosophy was that the engineers and technicians who were responsible for designing and building the electronics should be the ones to perform the integration and testing. This would assure, it was argued, that operations staff after construction would be thoroughly familiar with the electronics since the plan was that these same staff would be transitioning to operations. In the end, no separate systems group was formed. Reassigning existing staff to a systems group would have resulted in short handedness in maintaining the existing VLA, and the project did not have the means to hire additional staff to take up the slack. While a dedicated group of systems staff whose purpose was to outfit and test the electronics in every antenna likely would have resulted in schedule savings, the debate continues whether the project would have benefited significantly from a stronger systems presence. For example, not only did the Systems Engineer not have a dedicated systems group for which to direct the activities, but he often times found himself in the position of responsibility for tasks normally associated with a Project Engineer. While system integration and testing was overall very successful, few other areas of project systems management were supported. Ultimately, the system hardware was installed successfully, so the question remains whether it would have been worth the cost of the resources needed to staff a traditional systems group.

Another challenge was experienced in regards to general staffing. The project plan allowed for the hiring of additional staff for the life of construction. Termination of these staff is a common practice in industry once construction is completed. This came as no surprise to project management, and plans were made to assure a graceful downsizing of staff to coincide with the end of construction. None the less, It would be wise in the future for NRAO HR to make a provision so that particularly talented or otherwise useful project staff hired for construction could be retained, and that overall staffing levels do not suffer upon project completion. Post EVLA construction engineering staff numbers actually amounted to less than pre construction numbers – likely a result of the economic downturn in the US which coincided with the end of EVLA construction.

No major surprises were experienced during the project. This can partially be attributed to the high level of relevant staff experience which existed from the beginning of construction. Given this experience, it should not have been unexpected that the hardware system and subsystems did not perform successfully immediately after their initial installations. Some would contend this is quite natural with any project. Still, it came as somewhat a surprise to the project scientists and engineers when considerably more effort than anticipated was required to trouble shoot the first installed hardware.

As has previously been stated, EVLA construction, testing, and commissioning activities openly competed with VLA observing for observatory resources. Management of these priorities was sometimes complicated, even though a system existed to discuss and establish priorities. Furthermore, other activities in the observatory – smaller side projects for external customers – often flew under the radar and taxed project resources (staff). If an observatory resource management plan had been in place and active during construction, construction project schedules may not have been so tight at times and the overall construction experience may have come with less stress. In the end, though, the project goals and schedule were attained. The EVLA was delivered on time, on budget, and per specification. International collaboration proved very successful, and VLA observing throughout construction was maintained.

5.9 Post-project Tasks

All actions associated with EVLA hardware construction are completed, but work which was identified as a result of the array upgrade has been identified. This work includes

- ACU prototype development and, pending funding, upgrade for 28 antennas (Appendix 6.4)
- Receiver band retrofits for enhanced solar observing capability (Appendix 6.4)

Outstanding activities to improve overall success involve

- Modifications for C-band: Thermal gaps and polarizer will be installed by the Electronics Division as receivers undergo their routine maintenance cycle (Section 4.2.1.8).
- Modification for L-band: Thermal gaps will be installed by the Electronics Division as receivers undergo their routine maintenance cycle.
- A collaborative effort between Science and the Electronics Division is underway to assure antenna electronics gain changes remain linear to within 0.5% accuracy over an input power change of up to 15 dB (factor of 30, see Section 4.2.1.11).

5.10 Project Close Out Recommendations

It is recommended that project close out be approved for the Expanded Very Large Array construction project by the National Science Foundation, with the understanding that the project has fulfilled all of the requirements as documented and that the NSF is satisfied that all outstanding items have been satisfactorily addressed.

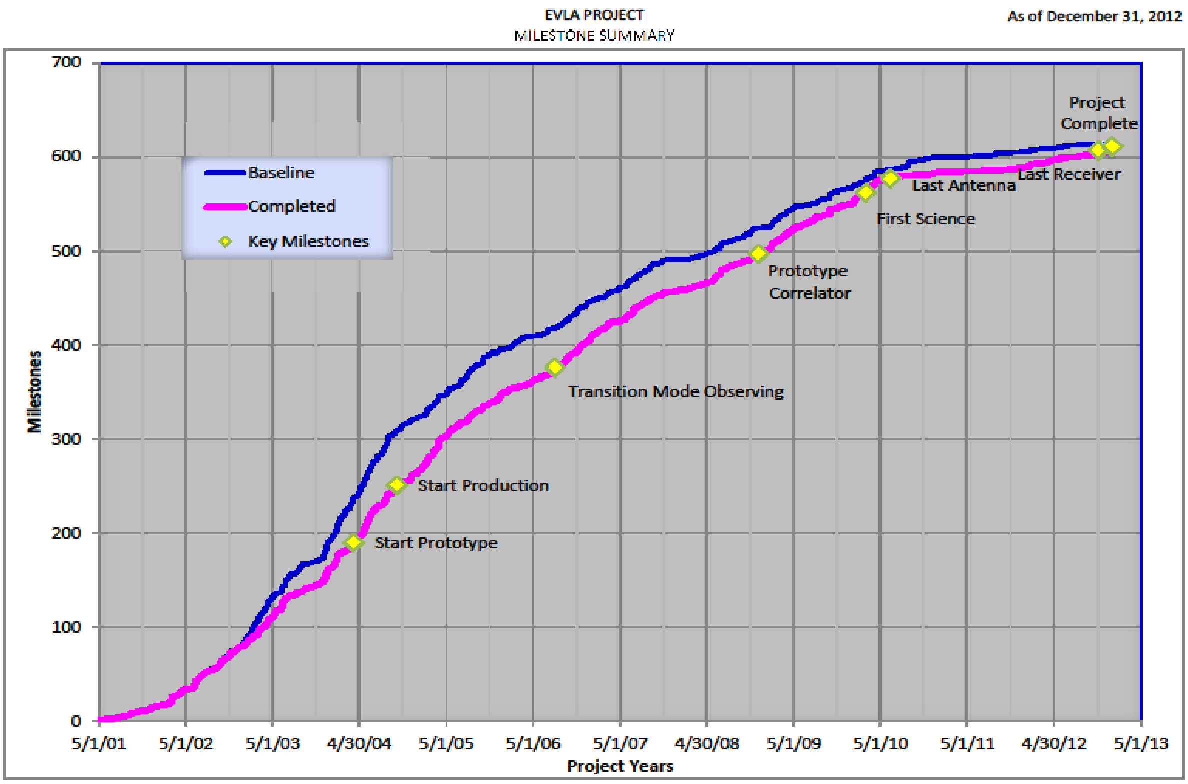
6 APPENDICES

6.1 Schedule

Appendix 6.1 A. EVLA Project WBS Level 2 tasks

WBS No.	Task Name	Task Description
6.01	Project Management	Project management including work definition, budget and schedule control. Advisory committee, design review and oversight activities.
6.02	System Integration and Testing	All system engineering activities during the design, integration, installation and test phases of the project. Management of the technical aspects of both the hardware and software systems. Provision of shared systems such as modules, racks and power supplies.
6.03	Civil Construction	Burial of the long-distance fiber optics cables along the arms of the array. Construction of a new shielded room to house the new EVLA correlator.
6.04	Antennas	Structural modifications to the VLA feed support structure on the antennas to allow installation of the new feed and receiver systems. Modifications to the vertex rooms on the antennas to allow installation of the new electronic systems.
6.05	Front End Systems	Design, construction and installation of all feeds and receivers for the eight new EVLA receiver bands. Modifications to the cryogenics systems on the antennas for compatibility with the new receivers.
6.06	Local Oscillator System	Provision of a central reference oscillator system and an antenna remote local oscillator (LO) system. Provision of a "round-trip-phase" monitoring system to stabilize the phase of the LO at each antenna.
6.07	Fiber Optic System	Provision of all fiber optics systems including the fiber, the optical transmitters and the optical receivers for LO distribution, IF transmission and M/C.
6.08	Intermediate Frequency System	Provision of all frequency converters required to convert the signal from the 8-12 GHz band at the output of each receiver to the 2-4 GHz baseband input to the digitizers. Provision of the wide band and narrow band digitizers. Provision of switching equipment required to direct the desired IF into each of the 8 digitizers.
6.09	Correlator	Construction and installation of the EVLA correlator, supplied by Canada, and NRAO interfaces.
6.10	Monitor and Control System	Provision of hardware and software for array monitor and control. Includes both the central computer system and the electronics system located in each module for interface to the M/C system.
6.11	Data Management and Computing	Provision of software and hardware for observation preparation and scheduling and for data post-correlation data processing. Includes a pipeline system for rapid image formation.
6.12	Education and Public Outreach	EVLA contribution of funds to NRAO's EPO program. No specific EPO work is done within the EVLA Project.

Appendix 6.1 B. Milestone Summary



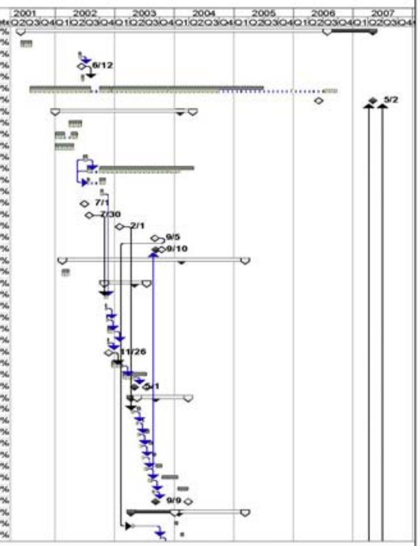
Appendix 6.1 C Key Milestones

WBS	Key Milestones	Baseline Start	Baseline Finish	Start	Finish
1.1.40.1	Start installation of fiber optics on Wye	11/4/02	11/4/02	11/4/02	11/4/02
1.1.40.2	Start prototype system lab integration & test	1/15/03	1/15/03	1/15/03	1/15/03
1.1.40.3	Install prototype system on test antenna	4/14/03	4/14/03	4/14/03	4/14/03
1.1.40.4	Complete electronics CDRs	1/7/04	1/7/04	5/21/04	5/21/04
1.1.40.5	Start electronics production	12/15/03	12/15/03	4/5/04	4/5/04
1.1.40.6	Start retrofitting antennas w/ new system	5/3/04	5/3/04	10/5/04	10/5/04
1.1.40.7	Start observing in transition mode	5/3/04	5/3/04	8/1/06	8/1/06
1.1.40.8	Test prototype correlator on 3 or 4 antennas	10/1/05	10/1/05	12/4/08	12/4/08
1.1.40.9	Start outfitting new correlator room	4/1/06	4/1/06	6/2/08	6/2/08
1.1.40.10	Start tests of 1st correlator subset at VLA	10/1/06	10/1/06	3/16/09	3/16/09
1.1.40.11	1st shared risk science w/ new correlator subset	4/1/07	4/1/07	3/1/10	3/1/10
1.1.40.12	New correlator declared operational	3/6/09	3/6/09	6/30/11	6/30/11
1.1.40.13	Last antenna retrofitted to EVLA design	8/27/10	8/27/10	6/11/10	6/11/10
1.1.40.14	Last receiver installed	6/1/12	6/1/12	12/28/12	12/28/12

Appendix 6.1 D. Level 4 Schedule

CIVIL CONSTROUCTION

ID	WBS	Task Name	Duration	Baseline Start	Baseline Finish	Start	Finish	% Complete
1	**3.1**	**Management/Subsystem Engineering**	**1471 d**	**6/4/01**	**7/27/06**	**6/4/01**	**5/2/07**	**100%**
2	3.1.5	Initial budget, labor & schedule estimate	9.6 w	6/4/01	8/10/01	6/4/01	8/10/01	100%
3	3.1.10	Preparation for installation internal CDR	2 w	5/27/02	6/7/02	5/27/02	6/7/02	100%
4	3.1.15	***Fiber Underground Installation CDR***	0 d	6/12/02	6/12/02	6/12/02	6/12/02	100%
5	3.1.20	CDR analysis & revisions	2 w	6/12/02	6/25/02	6/12/02	6/25/02	100%
6	3.1.25	Mgmt, R&D, documentation	1281.42 d	8/1/01	6/30/05	8/1/01	9/25/06	100%
7	3.1.100	Civil Construction Completed	0 d	6/5/06	6/5/06	5/2/07	5/2/07	100%
8	**3.5**	**Fiber Optic Cable**	**523 d**	**1/2/02**	**4/23/04**	**1/2/02**	**2/6/04**	**99%**
9	3.5.3.3	Develop array fiber installation plan	56 d	3/26/02	6/12/02	3/26/02	6/12/02	100%
10	3.5.3.6	Prep Hvac room for array termination panel	68.38 d	1/2/02	5/17/02	1/2/02	5/17/02	100%
11	3.5.3.9	Procure heavy equipment	80 d	1/2/02	4/25/02	1/2/02	4/25/02	100%
12	3.5.3.10	Outfit trencher - cable chute and cab enclosure	3 w	6/24/02	7/16/02	6/24/02	7/16/02	100%
13	3.5.3.12	Procure BOM for installation	387 d	7/17/02	4/28/04	7/17/02	2/6/04	100%
14	3.5.3.14	Fabricate fiber reel stands/trailers	3.71 mo	7/17/02	11/5/02	7/17/02	11/5/02	100%
15	3.5.3.16	Hire fiber crew	2 w	10/7/02	10/21/02	10/7/02	10/21/02	100%
16	3.5.3.18	*Contact State & Utilities on impending w-arm crossings*	0 d	7/1/02	7/1/02	7/1/02	7/1/02	100%
17	3.5.3.21	*Delivery fiber cable*	0 d	7/30/02	7/30/02	7/30/02	7/30/02	100%
18	3.5.3.24	*Contact State & Utilities on impending e-arm crossings*	0 d	2/1/03	2/1/03	2/1/03	2/1/03	100%
19	3.5.3.27	*Contact State & Utilities on impending n-arm crossings*	0 d	9/5/03	9/5/03	9/5/03	9/5/03	100%
20	3.5.3.28	Rock saw rental	0 d	10/16/03	10/16/03	9/10/03	9/10/03	100%
21	**3.5.5**	**Trench & Install FO Cable**	**496.4 d**	**2/14/02**	**3/10/05**	**2/14/02**	**2/13/04**	**100%**
22	3.5.5.5	Install CB manhole	1.4 mo	2/14/02	3/28/02	2/14/02	3/28/02	100%
23	**3.5.5.10**	**West Arm**	**125 d**	**10/30/02**	**7/15/03**	**10/30/02**	**5/1/03**	**100%**
24	3.5.5.12	Grade, trench path & locate U/G utils	3 w	10/30/02	11/19/02	10/30/02	11/19/02	100%
25	3.5.5.16	Pull fiber into array termination panel room	7 d	11/4/02	11/12/02	11/4/02	11/12/02	100%
26	3.5.5.18	Dismantle spur track & xptr fuel pump line	1 w	11/13/02	11/19/02	11/13/02	11/19/02	100%
27	3.5.5.20	Trench fiber from CB manhole to D2>C7	5 w	11/20/02	12/31/02	11/20/02	12/31/02	100%
28	3.5.5.22	Reconstruct spur track & fuel line	1 w	11/19/02	11/25/02	11/19/02	11/25/02	100%
29	3.5.5.23	Trench fiber to W10 & master pad complete	0 d	11/26/02	11/26/02	11/26/02	11/26/02	100%
30	3.5.5.24	Trench fiber from C7 to A5	8.8 w	12/13/02	2/19/03	12/13/02	2/18/03	100%
31	3.5.5.26	Trench fiber from A5 to A9	10 w	2/19/03	7/15/03	2/20/03	5/1/03	100%
32	3.5.5.27	West Arm trench fiber complete	0 d	7/15/03	7/15/03	5/1/03	5/1/03	100%
33	**3.5.5.30**	**East Arm**	**103 d**	**5/19/03**	**3/26/04**	**4/11/03**	**9/9/03**	**100%**
34	3.5.5.32	Grade, trench path & locate U/G utils	3 w	5/19/03	6/6/03	4/11/03	5/1/03	100%
35	3.5.5.36	Pull fiber into array termination panel room	3 d	6/23/03	6/25/03	5/16/03	5/20/03	100%
36	3.5.5.38	Trench fiber from CB manhole to D1>C5	2 w	6/26/03	7/30/03	5/21/03	6/3/03	100%
37	3.5.5.40	Trench fiber from C5 to RTE 52	2 w	7/31/03	8/20/03	6/4/03	6/17/03	100%
38	3.5.5.42	Trench fiber from RTE 52 to old RTE 60	2 w	8/21/03	9/8/03	6/18/03	7/1/03	100%
39	3.5.5.44	Trench fiber from old RTE 60 to A5	3 w	9/8/03	10/16/03	7/2/03	7/24/03	100%
40	3.5.5.46	Trench fiber from A5 to RTE 78	3.4 w	10/17/03	1/22/04	7/25/03	8/18/03	100%
41	3.5.5.48	Trench fiber from RTE 78 to A9	1.8 w	1/23/04	3/26/04	8/19/03	9/1/03	100%
42	3.5.5.49	East Arm trench fiber complete	0 d	3/26/04	3/26/04	9/9/03	9/9/03	100%
43	**3.5.5.50**	**North Arm**	**198 d**	**1/5/04**	**3/10/05**	**4/11/03**	**1/30/04**	**100%**
44	3.5.5.52	Grade, trench path & locate U/G utils	3 w	1/5/04	1/23/04	4/11/03	5/1/03	100%
45	3.5.5.56	Pull fiber into array termination panel room	4 d	2/9/04	2/27/04	10/6/03	10/9/03	100%



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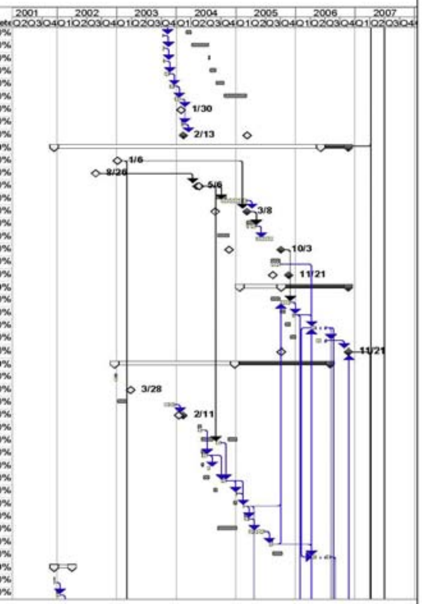
ID	WBS	Task Name	Duration	Baseline Start	Baseline Finish	Start	Finish	% Complete
46	3.5.5.58	Dismantle main line track @ wye	2 d	3/1/04	4/2/04	10/10/03	10/13/03	100%
47	3.5.5.60	Trench fiber from CB manhole to D2	2 d	4/5/04	7/16/04	10/14/03	10/15/03	100%
48	3.5.5.62	Reconstruct main line track	1 w	7/19/04	7/23/04	10/16/03	10/22/03	100%
49	3.5.5.64	Trench fiber from D2 to B6	4 w	7/26/04	8/30/04	10/23/03	11/19/03	100%
50	3.5.5.66	Trench fiber from B6 to A5	4 w	8/31/04	10/20/04	11/20/03	12/19/03	100%
51	3.5.5.68	Trench fiber from A5 to A9	3.8 w	10/21/04	3/10/05	12/22/03	1/22/04	100%
52	3.5.5.69	East Arm trench fiber complete	0 d	1/30/04	1/30/04	1/30/04	1/30/04	100%
53	3.5.5.70	Trench fiber on South arm	2 w	2/2/04	2/13/04	2/2/04	2/13/04	100%
54	3.5.5.80	Array fiber burial completed	0 d	3/10/05	3/10/05	2/13/04	2/13/04	100%
55	**3.10**	**New Correlator Room**	**1228 d**	**12/14/01**	**6/5/06**	**12/14/01**	**11/21/06**	**100%**
56	3.10.1	***Propose relocation of Mod Comps, tape drives, computer***	0 d	1/6/03	1/6/03	1/6/03	1/6/03	100%
57	3.10.2	***Interim location of LO fiber panel determined***	0 d	8/26/02	8/26/02	8/26/02	8/26/02	100%
58	3.10.3	Determine new location of ModComps, Miranda	0 d	5/21/04	5/21/04	5/6/04	5/6/04	100%
59	3.10.3	Develop correlator shielded room specifications	5 mo	9/2/04	11/2/04	10/4/04	3/8/05	100%
60	3.10.6	Shielded room spec's written	0 d	8/27/04	8/27/04	3/8/05	3/8/05	100%
61	3.10.7	RFQ shielded room	7.9 w	3/9/05	5/4/05	3/9/05	5/4/05	100%
62	3.10.8	Order shielded room	14 w	9/10/04	11/19/04	5/4/05	8/15/05	100%
63	3.10.9	Shielded room delivered	0 d	11/19/04	11/19/04	10/3/05	10/3/05	100%
64	3.10.11	Order shielded room floor	8 w	8/2/05	9/27/05	8/2/05	9/27/05	100%
65	3.10.13	RFQ FM200 fire suppression system	0 d	8/15/05	8/15/05	11/21/05	11/21/05	100%
66	**3.10.5**	**Shielded Room**	**283 d**	**1/24/05**	**10/5/05**	**10/3/05**	**11/21/06**	**100%**
67	3.10.5.2	Erect new correlator shielded room	2 mo	8/2/05	9/28/05	10/3/05	11/29/05	100%
68	3.10.5.3	RFI test shielded room	0.5 mo	9/29/05	10/28/05	12/12/05	12/28/05	100%
69	3.10.5.10	Install shielded room floor	2.86 mo	10/31/05	11/30/05	4/10/06	7/6/06	100%
70	3.10.5.14	Install FM200 plumbing, alarms, interlocks	1.96 mo	12/1/05	1/3/06	5/9/06	7/10/06	100%
71	3.10.5.16	Shielded room available	0 d	10/5/05	10/5/05	11/21/06	11/21/06	100%
72	**3.10.10**	**Remodeling**	**900 d**	**12/19/02**	**12/24/04**	**12/19/02**	**8/2/06**	**100%**
73	3.10.10.1	Relocate Fiber group - cryo to CB	1.4 w	12/19/02	1/6/03	12/19/02	1/1/03	100%
74	3.10.10.2	LO panel installed in interim location	0 d	3/28/03	3/28/03	3/28/03	3/28/03	100%
75	3.10.10.4	Prepare old correlator room for EVLA equipment	2.1 mo	1/7/03	3/6/03	10/21/03	12/23/03	100%
76	3.10.10.6	Old correlator room ready for EVLA equipment	0 d	1/16/04	1/16/04	2/11/04	2/11/04	100%
77	3.10.10.7	Order mat'ls for new Fiber-lab	3.5 w	5/12/04	6/2/04	5/12/04	6/7/04	100%
78	3.10.10.8	Order mat'ls to move ModComps & FO-lab	1 mo	6/4/04	1/7/05	9/1/04	9/30/04	100%
79	3.10.10.9	Remodel CB Annex - Fiber Lab	1 mo	6/3/04	7/1/04	6/7/04	7/8/04	100%
80	3.10.10.10	Move fiber lab to new location	2 w	6/4/04	6/17/04	7/12/04	7/23/04	100%
81	3.10.10.12	Prepare space to move array computers	1 mo	6/18/04	8/18/04	10/4/04	11/2/04	100%
82	3.10.10.14	Relocate tape storage	0.8 w	8/19/04	9/9/04	12/31/04	1/6/05	100%
83	3.10.10.18	Relocate Array computers	1 w	12/16/04	1/5/05	2/14/05	2/18/05	100%
84	3.10.10.20	Clearout old computer equipment, etc.	1 mo	2/22/05	3/22/05	2/22/05	3/22/05	100%
85	3.10.10.22	Prepare area for new correlator installation	3 mo	9/10/04	1/5/05	3/23/05	6/23/05	100%
86	3.10.10.24	Grind & level floor/Core drill floor	3 w	7/25/05	8/12/05	7/25/05	8/12/05	100%
87	3.10.10.26	Design & fabricate equipment stands	3.81 mo	8/15/05	10/12/05	4/10/06	8/2/06	100%
88	**3.10.15**	**RFI Shielded Test Chamber**	**71 d**	**12/14/01**	**4/1/02**	**12/14/01**	**4/1/02**	**100%**
89	3.10.15.5	Ship chamber assembly to VLA from GB	2 d	12/14/01	12/17/01	12/14/01	12/17/01	100%
90	3.10.15.10	Prepare VLA warehouse space for chamber	0.76 mo	12/26/01	1/18/02	12/26/01	1/18/02	100%



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Task | Baseline | Milestone | Baseline Milestone | Summary | Baseline Summary | Split | External Tasks | Project Summary | Progress

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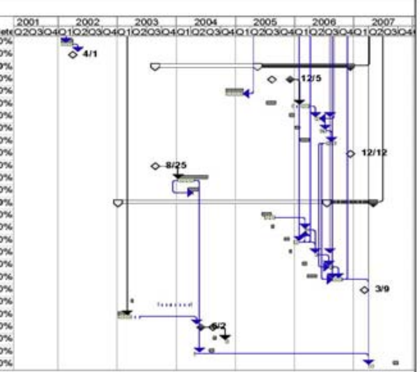
ID	WBS	Task Name	Duration	Baseline Start	Baseline Finish	Start	Finish	% Complete
91	3.10.15.15	Assemble shielded chamber	2.33 mo	1/21/02	4/1/02	1/21/02	4/1/02	100%
92	3.10.15.20	Shielded test chamber complete	0 d	4/1/02	4/1/02	4/1/02	4/1/02	100%
93	**3.15**	**CB HVAC**	**820 d**	**8/25/03**	**5/17/05**	**8/25/03**	**12/12/06**	**100%**
94	3.15.3	RFQ HVAC & plumbing	0 d	8/15/05	8/15/05	12/5/05	12/5/05	100%
95	3.15.1	Rework ductwork, piping, etc. for array computers	3.57 mo	11/1/04	2/18/05	11/1/04	2/18/05	100%
96	3.15.3a	Order HVAC for shielded room	3.46 mo	7/11/05	9/7/05	12/16/05	4/3/06	100%
97	3.15.5	Install new hvac units in shielded room	1 mo	12/1/05	1/3/06	5/9/06	6/7/06	100%
98	3.15.7	Install hvac plumbing	1.21 mo	1/4/06	2/1/06	6/8/06	7/17/06	100%
99	3.15.9	Install new ductwork, piping, etc. in shielded room area	2 mo	2/2/06	4/4/06	7/17/06	9/14/06	100%
100	3.15.7	Correlator room HVAC operational	0 d	12/12/06	12/12/06	12/12/06	12/12/06	100%
101	3.15.2	***Develop CB interim cooling plan***	0 d	8/25/03	8/25/03	8/25/03	8/25/03	100%
102	3.15.4	Replace CB existing chillers	3.34 mo	1/12/04	7/22/04	1/12/04	4/21/04	100%
103	3.15.6	Piping modifications in mechanical room	3 d	3/11/04	5/18/04	4/12/04	4/14/04	100%
104	**3.20**	**Power Distribution**	**1077 d**	**1/6/03**	**7/19/06**	**1/6/03**	**5/2/07**	**100%**
105	3.20.10	Develop BOM/Order electrical material	2 mo	6/13/05	8/11/05	7/1/05	8/31/05	100%
106	3.20.12	Install RFI power filters	2 w	8/12/05	8/25/05	3/7/06	3/20/06	100%
107	3.20.14	Install main power feeds & panels	1 mo	10/31/05	11/30/05	12/28/05	1/27/06	100%
108	3.20.17	Install grounding for shielded room & flooring	2 w	12/1/05	12/14/05	5/9/06	5/22/06	100%
109	3.20.20	Install conduit & cable in floor	1 mo	2/17/06	3/17/06	7/31/06	8/29/06	100%
110	3.20.22	Install shielded room lighting, outlets & hvac pwr	2 mo	3/20/06	5/17/06	8/23/06	10/23/06	100%
111	3.20.23	Install correlator 48v DC power plant	0 d	3/9/07	3/9/07	3/9/07	3/9/07	100%
112	3.20.2	Provide power to Master LO racks	28.3 w	3/28/03	4/10/03	9/8/03	4/5/04	100%
113	3.20.4	Develop CB 2nd floor power distribution plan	4.69 mo	1/6/03	3/5/03	1/6/03	5/27/03	100%
114	3.20.6	Procure & install new CB transformer	0 mo	8/13/04	8/13/04	6/2/04	6/2/04	100%
115	3.20.8	Relocate CB 2nd floor distribution panel	3 w	8/16/04	9/3/04	10/29/04	11/18/04	100%
116	3.20.10	Provide power to replacement chillers	2 d	7/23/04	8/20/04	4/21/04	4/23/04	100%
117	3.20.25	Revisions to CB UPS system	1 mo	9/3/07	11/1/07	4/3/07	5/2/07	100%

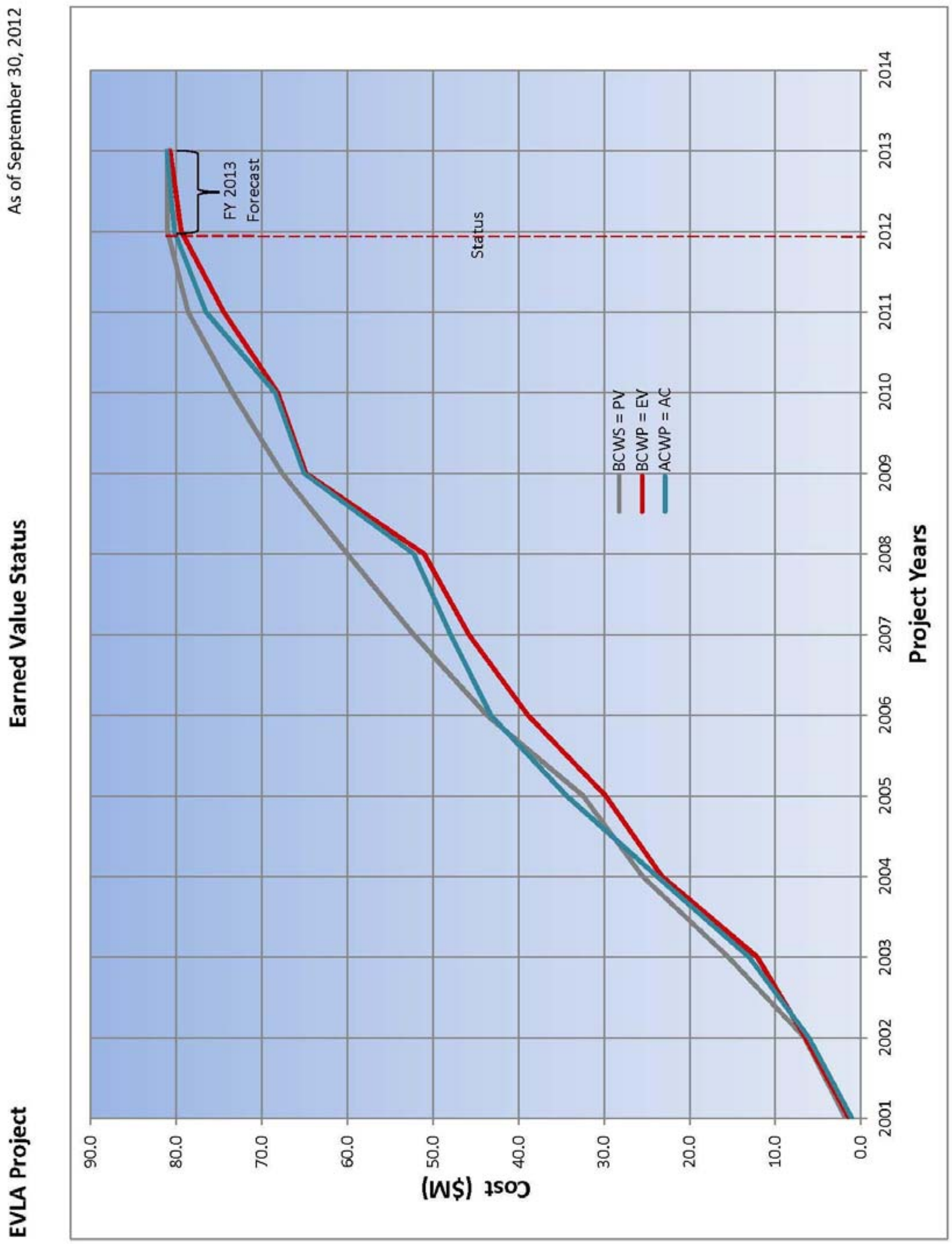


Project: civil_v10
Date: 2/7/13

Task | Baseline | Milestone | Baseline Milestone | Summary | Baseline Summary | Split | External Tasks | Project Summary | Progress

EVLA PROJECT | Page 3

Appendix 6.1 E. Performance Metrics Over Life of Project



6.2 Budget and WBS

Appendix 6.2 A. Level 2 WBS (w/ Level 4 Task List)

WBS			TASK NAME
6.01	**C. Langley**		**Project Management**
	6.01.01		Management/Subsystem Engineering
	6.01.06		Project Book, Manuals and Documentation
	6.01.10		Office Equipment & Supplies
	6.01.15		Drafting and Lab Services
	6.01.20		Advisory Comm Support
6.02	**Jackson/Butler**		**System Integration and Testing**
	6.02.01		Management/Subsystem Engineering
		6.02.01.05	Block Diagrams for Systems & Subsystems
		6.02.01.10	Engineering Performance Specifications
		6.02.01.15	Basic Engineering Interface Specifications
	6.02.05		Test and Lab Equipment
		6.02.05.05	Production Test and Lab Equipment, FO
		6.02.05.10	Production Test and Lab Equipment, FE
		6.02.05.15	Production Test and Lab Equipment, LO
		6.02.05.20	Test and Lab Equipment General
	6.02.10		Power Supply System
		6.02.10.05	Central Electronics Room
		6.02.10.10	Master LO Power Supply
		6.02.10.15	Antenna Vertex Room Power Supply
		6.02.10.20	Antenna Pedestal Room Power Supply
	6.02.15		Site RFI Characterization & Suppression
		6.02.15.05	Facilities Development
		6.02.15.09	Limits for RFI Emmission Levels
		6.02.15.10	Acceptance Test Development
		6.02.15.15	RFI/EMC Analysis of Electronics & Computers
		6.02.15.20	Site RFI Mitigation
	6.02.16		External RFI & System Immunity
		6.02.16.05	Measurement of PFD/BW Levels of RFI at Each Band
		6.02.16.10	EVLA Antenna Sidelobe Gain Patterns 2-120 Degrees
		6.02.16.15	Distribution of Gains, SNRs & Headroom of existing Rcvrs
		6.02.16.20	Spec's for Distribution of System/Subsystem Gains, SNRs
		6.02.16.25	Spec's/Development of RFI Filters for Rcvrs
		6.02.16.30	Spec's/Development of RFI Filters in IF System
	6.02.20		Scientific Support
		6.02.20.05	Development of Scientific Performance Specifications

		6.02.20.10	Spec's for Minimum Limits for Angular Separation from Satellites
	6.02.25		Modules, Bins and Racks
	6.02.30		Transition Planning
6.03	**G. Stanzione**		**Civil Construction**
	6.03.01		Management/Subsystem Engineering
	6.03.05		FO Cable, Trench, Install
		6.03.05.05	FO Cable, Trench and Install (200 kft)
		6.03.05.10	FO Cable (550kft)
	6.03.10		New Correlator Room
		6.03.10.05	New Correlator Shielded Chamber
		6.03.10.10	Remodeling and Demolition
		6.03.10.15	IPG Shielded Chamber
		6.03.10.20	Power Distribution
		6.03.10.25	Install New Correlator
	6.03.15		Power Distribution
	6.03.20		HVAC and Fire Suppression
6.04	**J. Ruff/L. Serna**		**Antennas**
	6.04.01		Management/Subsystem Engineering
	6.04.02		Precision Machining
	6.04.05		Feed Cone and Towers
	6.04.10		Antenna Structural Modifications
	6.04.15		Antenna Electrical & HVAC Service
		6.04.15.05	Antenna Electrical
		6.04.15.10	Antenna HVAC
	6.04.20		Feed Moisture Control and Pointing Improvements
6.05	**C. Kutz**		**Front End Systems**
	6.05.01		Management/Subsystem Engineering
	6.05.05		Card Cage, Controllers
		6.05.05.01	Front End Card Cage
		6.05.05.02	FE Control Modules
		6.05.05.03	F-Rack
	6.05.RX		Receivers
		6.05.05.05	L Band
		6.05.05.10	S Band
		6.05.05.15	C Band
		6.05.05.20	X Band
		6.05.05.25	Ku Band
		6.05.05.30	K Band
		6.05.05.32	K Band Completion (7 units)
		6.05.05.35	Ka Band
		6.05.05.40	Q Band
		6.05.05.45	Q Band Completion (5 units)
	6.05.10		Feeds
		6.05.10.05	L Band
		6.05.10.10	S Band

		6.05.10.15	C Band
		6.05.10.20	X Band
		6.05.10.25	Ku Band
		6.05.10.32	K Band
		6.05.10.30	K Band Completion (7 units)
		6.05.10.35	Ka Band
		6.05.10.40	Q Band
		6.05.10.45	Q Band Completion (5 units)
	6.05.30		Cryogenics
		6.05.30.05	Vacuum Pump and Manifolds
		6.05.30.10	Compressors & He Lines
		6.05.30.15	Refrigerators
6.06	**T. Cotter**		**Local Oscillator System**
	6.06.01		Management/Subsystem Engineering
	6.06.05		Master LO System
		6.06.05.05	H Maser Frequency Standard (&Rb)
		6.06.05.10	PPS Generator & Distributor
		6.06.05.25	LO Ref Generator
		6.06.05.30	LO ref Distributor - Control Bldg
		6.06.05.35	LO Driver
		6.06.05.40	512 MHz Offset Generator
	6.06.07		Central Antenna System
		6.06.07.05	Round Trip Phase Receiver
	6.06.10		12-20 GHz Synthesizer
	6.06.15		10.8-14.8 GHz Synthesizer
	6.06.20		Antenna Reference System
		6.06.20.05	Antenna LO Reference Generator
6.07	**D. Gerrard**		**Fiber Optic System**
	6.07.01		Management/Subsystem Engineering
	6.07.05		IF Fiber System
		6.07.05.05	Formatter
		6.07.05.10	Deformatter
		6.07.05.15	Laser Transmitter
	6.07.10		Infrastructure and Antenna Outfitting
		6.07.10.05	Fiber Infrastructure
		6.07.10.10	Antennas
	6.07.15		Samplers & MCB
		6.07.15.05	Monitor and Control
		6.07.15.10	2-4 GHz Sampler
		6.07.15.15	1 GHz Sampler
	6.07.20		LO Fiber System
		6.07.20.10	LO/Reference
6.08	**T. Cotter**		**Intermediate Frequency System**
	6.08.01		Management/Subsystem Engineering
	6.08.05		Switches and RF Cabling

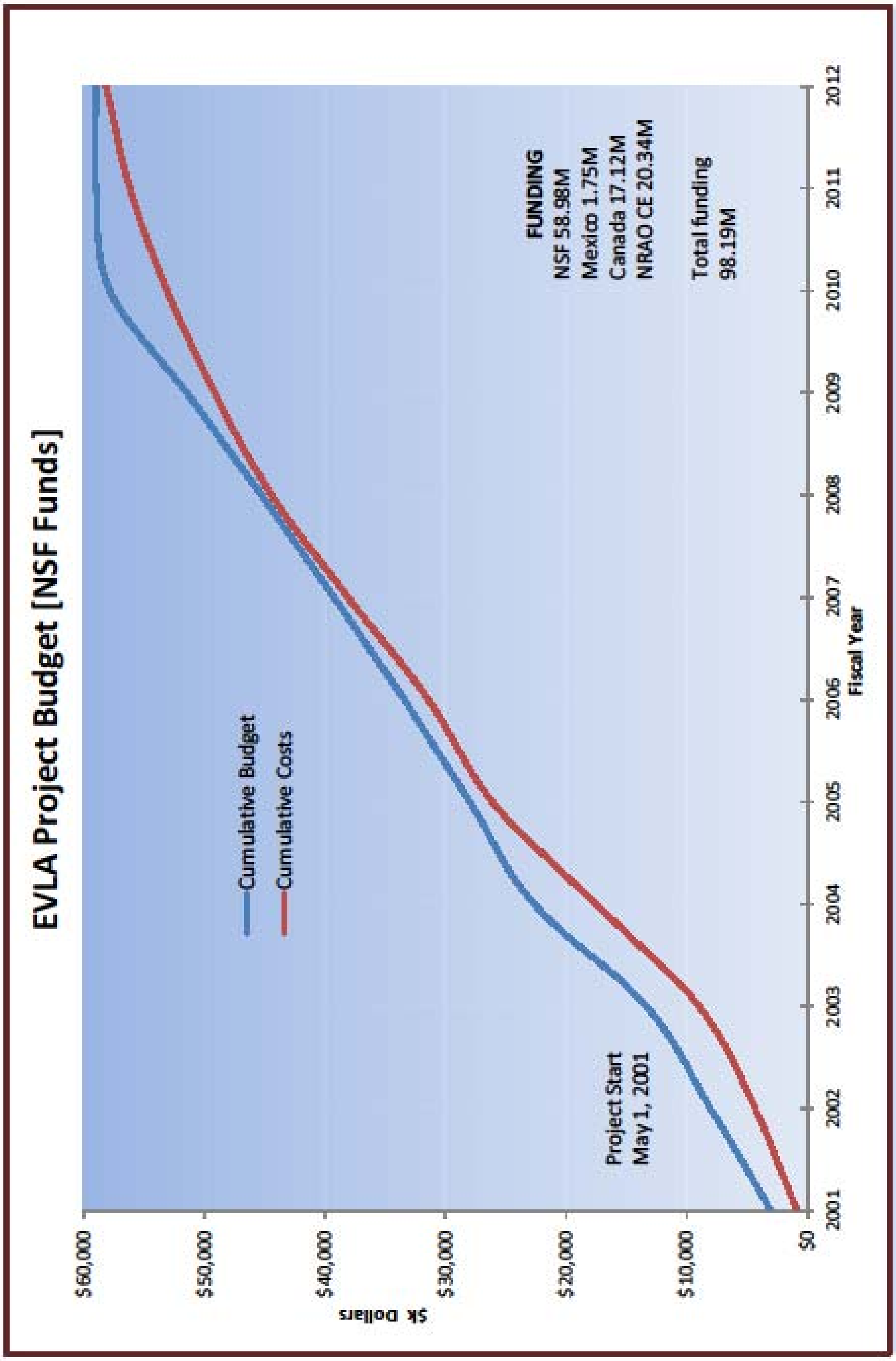
	6.08.10		4/P & L/S/C-Band Converters
	6.08.15		U/X Converter Module
	6.08.20		IF Down Converter
6.09	**B. Carlson/M. Revnell**		**Correlator**
	6.09.01		Management/Subsystem Engineering
	6.09.05		NRAO Correlator Interface
	6.09.10		Pre-project Tooling/Setup
	6.09.15		Station Board H/W Development
		6.09.15.02	Station Board
		6.09.15.05	FIR Filter Chip Development
		6.09.15.10	Course Delay Module
	6.09.20		Sub-band Distribution Backplane
	6.09.25		Station Data Fanout Board
	6.06.30		Baseline Entry Backplane
	6.09.35		Baseline Board H/W Development
		6.09.35.02	Baseline Board
		6.09.35.05	Correlator Chip Development
	6.09.40		Phasing Board
	6.09.45		Phasing Board Entry Backplane H/W Deployment
	6.09.50		TIMECODE Generator Box H/W Deployment
	6.09.55		Real-time S/W Development
	6.09.60		System Design (Racks, Main Pwr, Cabling, Computer)
	6.09.65		Production Model Test/Burn-in
	6.09.70		System Integration & Test (Pentecton)
	6.09.75		System Integration & Test (VLA off-line)
	6.09.80		Online Debug, Test (VLA on-line)
6.10	**B. Butler**		**Monitor & Control System**
	6.10.01		Management/Subsystem Engineering
	6.10.05		M&C Electronic Hardware
		6.10.05.05	Physical Interface
		6.10.05.10	Utility Module
	6.10.10		M&C Network, Hardware & Software
	6.10.15		M&C Computing Systems Hrdwre & Sftwre
	6.10.20		M&C EVLA Software
		6.10.20.05	Stabilization of the VLA
		6.10.20.10	Requirements
		6.10.20.15	High Level Software Architecture & Design
		6.10.20.20	Test & Devel Support, Enhanced Antennas
		6.10.20.25	Mid Level Analysis & Design
		6.10.20.30	Test & Devel Support, Correlator
		6.10.20.35	Detailed Design & Coding
	6.10.25		Switch Interface Module
	6.10.30		M&C Transition Hardware
6.11	**B. Butler/J. Robnett**		**Data Management and Computing**
	6.11.01		Management/Subsystem Engineering

	6.11.05		Proposal Preparation and Submission
		6.11.05.05	Requirements
		6.11.05.10	Proposal submission toolkit
	6.11.10		Observation Preparation Software
		6.11.10.05	Requirements
		6.11.10.10	Observation description toolkit
		6.11.10.15	Observation planning toolkit
	6.11.15		Observation Scheduling
		6.11.15.05	Requirements
		6.11.15.10	Observation scheduling toolkit
		6.11.15.15	Observing toolkit
		6.11.15.20	EVLA-specific Observing toolkit
	6.11.20		Image Pipeline
		6.11.20.05	Requirements
		6.11.20.10	Pipeline toolkit
		6.11.20.15	Pipeline heuristics
		6.11.20.20	EVLA-specific pipeline heuristics
	6.11.25		Data Archive
		6.11.25.05	Requirements
		6.11.25.10	Archive toolkit
	6.11.30		Data Post Processing
		6.11.30.05	Requirements
		6.11.30.10	CASA package (formerly EVLA AIPS++)
	6.11.35		Networking
		6.11.35.05	Upgrade Servers
		6.11.35.10	Replace copper by optical fiber
		6.11.35.15	Upgrade Clients
		6.11.35.20	Update VLA/AOC Datalink
		6.11.35.25	Update Non-Operations VLA Network
		6.11.35.30	VOIP Antenna Phones
	6.11.40		Computing Hardware
		6.11.40.05	Development hardware
		6.11.40.10	Archive hardware
		6.11.40.15	Data Reduction Hardware
	6.11.45		Correlator Backend Network
		6.1145.05	Correlator Backend Network
6.12			**Education and Public Outreach**
	6.12.05		EVLA Contribution to new Visitor Center
6.13	**C. Langley**		**Project Contingency**
	6.13.05		Unallocated Funds

Appendix 6.2 B. Project Cost Summary

WBS	Task Name	Actual FY2001	Actual FY2002	Actual FY2003	Actual FY2004	Actual FY2005	Actual FY2006	Actual FY2007	Actual FY2008	Actual FY2009	Actual FY2010	Actual FY2011	Actual FY2012	Budget FY2013	Totals
6.01	Project Management	77.3	175.2	119.3	273.9	148.2	409.1	-2.0	116.3	167.9	155.6	55.6	40.5		1737
6.02	System Integration & Testing	212.0	478.0	236.4	746.1	571.2	452.9	314.1	274.7	74.6	36.6	10.7	85.9		3493
6.03	Civil Construction	0.2	252.0	40.1	229.0	197.4	326.9	120.8	21.1	7.0	45.3	38.1	51.6		1330
6.04	Antennas	0.0	46.7	98.5	497.2	172.3	136.9	154.2	113.3	93.2	116.1	66.8	111.5		1607
6.05	Front End Systems	385.5	114.7	596.5	1312.7	1894.4	504.7	805.7	1648.4	1153.9	1179.8	406.5	497.8		10501
6.06	Local Oscillator System	14.1	292.4	253.0	1188.4	357.9	307.1	393.9	342.1	160.5	89.8	68.6	76.9		3545
6.07	Fiber Optic System	4.7	603.8	735.5	1175.6	685.8	723.6	1224.0	427.5	354.1	340.8	184.9	172.3		6633
6.08	Intermediate Frequency System	0.0	105.5	327.5	215.4	819.9	353.3	513.3	639.9	218.4	46.5	103.2	476.8		3820
6.09	Correlator (Canadian)	277.0	336.5	192.7	759.8	883.1	3748.8	3979.0	1539.0	117.5	0.0	0.0	0.0		11833
6.09	NRAO Correlator Interface								6.3	86.0	9.7	50.0	31.8		184
6.10	Monitor & Control System	0.0	209.2	255.8	367.0	540.8	603.9	257.8	214.3	45.3	60.4	34.8	291.7		2881
6.11	Data Management & Computing	2.8	0.2	219.1	180.8	37.2	31.9	40.4	85.8	46.9	240.3	269.3	564.2		1719
6.12	Education & Public Outreach	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.6		91
6.13	Contingency Funds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	688.8	689
	M&S Total	974	2613	3074	6946	6308	7598	7801	5429	2525	2321	1288	2492	689	50060
	Travel	7	94	73	80	109	78	47	79	63	40	2	18	0	695
	Direct Labor	126	1115	1689	2297	3066	3122	2796	2382	2272	1550	835	425	130	21807
	NRAO Indirect Labor	195	1549	2317	2186	2000	1794	2495	2479	2347	1232	943	797	0	20336
	NRAO Wages & Benefits	321	2664	4006	4483	5066	4917	5291	4861	4620	2782	1778	1223	130	42143
	Canadian Labor	267	353	551	687	743	676	781	801	424	0	0	0	0	5283
	Sub Total	1569	5724	7704	12196	12226	13270	13920	11170	7632	5143	3069	3733	819	98181
	Contingency	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Redirected NRAO Effort	-195	-1549	-2317	-2186	-2000	-1794	-2495	-2479	-2347	-1232	-943	-797	0	-20336
	Canadian Contribution	-544	-690	-744	-1446	-1626	-4425	-4760	-2340	-542	0	0	0	0	-17116
	Mexican Contribution						-1747								-1747
	EVLA Project Funds	830	3486	4644	8563	8600	5304	6665	6351	4743	3911	2126	2935	819	58983
	Carryover to next yr	2170	3685	4363	5140	1880	2017	1186	845	2292	4757	3761	826	7	
	Carryover from prior yr		-2170	-3685	-4363	-5140	-1880	-2017	-1186	-845	-2292	-4757	-3761	-826	
	NSF Funded	3000	5000	5322	9340	5340	5440	5835	6010	6190	6376	1130	0	0	58983
		FY2001	FY2002	FY2003	FY2004	FY2005	FY2006	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012		Totals

CURRENT FTE TOTALS	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Total
EVLA Project	1.4	14.1	27.3	34.9	39.9	39.4	37.1	33.9	30.1	21.5	13.0	9.3	0.6	302.5
Off Budget (contributed effort)	3.1	19.8	28.5	32.6	32.3	33.0	34.1	32.0	30.4	17.4	12.7	6.5	0.0	282.4
Total FTEs	4.6	33.9	55.8	67.5	72.1	72.4	71.2	65.9	60.5	38.9	25.7	15.9	0.6	584.9



As of September 30, 2012

Appendix 6.2 C. WBS Cost Data Sheet

EVLA Cost Data Sheet Last Printed: 02/07/13 Note: All monetary amounts are listed in $K

Task Name: L-Band Receiver
WBS Number: 8.05.05.05 **Acct #** 855.XXXX.050505

Name/Estimator: Daniel J. Mertely Phone: 505-835-7128
Basis of Estimate: Scaled K-band histo Version Date: 30-Sep-11

Assigned Risk Factors:			**Multipliers for Contingency:**		
Technical	2.0	(1,2,3,4,6,8,10,15)	Technical Multiplier:	2.0	(2,4)
Cost	1.0	(1,2,3,4,6,8,10,15)	Cost Multiplier:	1.0	(1,2)
Schedule	2.0	(2,4,8)	Calc. Contingency:	7.0%	

	M&S	Labor	EVLA Funds Only M&S	EVLA Funds Only Labor	
% Complete	80.0%	95.3%			
Budget	675.0	777.5	675.0	371.6	Total Budget
PV	675.0	777.5	-523.9	-371.6	ITD Expended
Actual	**523.9**	**740.9**	-151.1	0.0	FY12 Allocated
Earned Value	540.0	740.9	0.0	0.0	Remaining funds
SV	-135.0	-36.6	SPI 0.9		
CV	16.1	0.0	CPI 1.0		
	As of Sept 30, 2011		<1.0 = overrun		

Task Description: *(Text for the WBS dictionar* L-Band. Modify 30 current VLA L-band receiver systems. Increase instantaneous RF bandwidth from 1350-1750 MHz to 1000-2000 MHz. Requires new wideband OMT design. A coaxial hybrid coupler will be utilized as the circular polarizer. NOTE: External LSC-band converter module provided by LO/IF group.

Labor: In Person Months

Employee Name	SG	Job	SS	2001	]	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total FTE's
Paul Lilie	2		EV		2.4	4.9	4.6	3.2	6							1.8
Hollis Dinwiddie	3		EV			0.1	0.6	0.5	0.5	4.0	2.0	1.0				0.7
Craig Hennies	4		EV			0.1				1.0	3.5	3.5	3.5	3.0		1.2
David McKee	4		EV				0.1	1.0	1.0							0.2
Carlos Marrero	4		EV					2.0		4.0	3.0	3.0	2.0			1.2
Michael Zamora	4		EV													0.0
Mike Stennes (GB)	2		EV													0.0
Sri Srikanth	2		CV													0.0
Gordon Coutts	2		ED						3.4	2.5	2.0	2.0	2.0	2.0		1.2
Charles Barham	3		ED													0.0
Everett Callan	3		ED													0.0
Frank Broaddus	3		ED													0.0
Jim Gregg	3		ED													0.0
Robert Hayward	3		ED		1.0	0.7	0.3	0.3	2.0	2.0	2.0	1.0	1.0	0.5	2.0	1.1
Rudy Latasa	3		ED													0.0
Dan Mertely	3		ED		0.3	0.6	0.3	0.3								0.1
Robert Ridgeway	3		ED													0.0
Travis Noland	4		EV													0.0
John McClendon	3		ED													0.0
Brent Willoughby	3		ED					1.0								0.1
Dan Dillon	4		ED					2.0	3.0	2.0	5.0	5.0	5.0	2.2	6.0	2.5
VLBA Techs (Hicks)	4		ED			1.5	2.3	3.0	6.0							1.1
Ed Morgan	3		ED													0.0
Patty Lindsey	4		ED													0.0
Jake Scarborough	3		EV													0.0
Robert Stupak	3		EV													0.0
Charles Kutz	2		ED					0.3	0.3	0.1	0.1	0.1	0.1	0.1		0.1
Juan Salazar	4		EV													0.0
Stacy Knighton	4		EV													0.0
Michael Zamora	4		ED													0.0
Labor Totals ($K):				**0.0**	**29.9**	**59.9**	**59.4**	**77.5**	**144.9**	**89.0**	**90.5**	**78.3**	**68.1**	**43.5**	36.6	777.5
TOTAL FTEs:				**0.0**	**0.3**	**0.7**	**0.7**	**1.1**	**1.9**	**1.3**	**1.5**	**1.3**	**1.1**	**0.7**	0.7	11.2
TOTAL EV FTEs:				**0.0**	**0.2**	**0.4**	**0.4**	**0.6**	**0.6**	**0.8**	**0.7**	**0.6**	**0.5**	**0.3**	0.0	5.0
Off Budget FTEs:				**0.0**	**0.1**	**0.2**	**0.2**	**0.6**	**1.2**	**0.6**	**0.8**	**0.7**	**0.7**	**0.4**	0.7	6.1
TOTAL EV LABOR ($k):				**0.0**	**22.0**	**45.9**	**46.4**	**44.6**	**62.1**	**44.8**	**38.7**	**32.6**	**22.4**	**12.2**	0.0	371.6

Materials: In $K

Material Description:	2001 Cost	2002 Cost	2003 Cost	2004 Cost	2005 Cost	2006 Cost	2007 Cost	2008 Cost	2009 Cost	2010 Cost	2011 Cost	2012 Cost	Total Cost
Custom Waveguide Components			0.0	0.0	0.0	0.0		4.4	44.4				48.9
Copper plating					0.0	0.0		1.6	19.5	6.0			27.2
Outsource machining									55.6	10.6	10.0		76.2
Prototype Components		3.0	10.7	3.4	6.8	20.9	29.8						74.5
Up Front Components						5.0	11.3	17.3	62.5	39.4	35.5		170.9
Production Components						0.0		11.1		29.2	8.0		48.3
Spares & Retrofit Components										0.0	0.0		0.0
Additional solar costs													0.0
LNA's (full cost recovery, out-sourced)					2.9	1.8	19.7	11.9	1.7	10.0	14.8		62.7
New H/C Loads (2xOMT,including m							5.1						5.1
OMT prototype fab (6/8/05 new requ						0.0	10.0						10.0
Thermal gap													0.0
L-Band C2C Summary Items												151.1	151.1
Materials Total ($K):	**0.0**	**3.0**	**10.7**	**3.4**	**9.6**	**27.7**	**75.9**	**46.3**	**183.7**	**95.3**	**68.3**	151.1	675.0

Contracts (Committed):

Contract Description:	2001 Cost	2002 Cost	2003 Cost	2004 Cost	2005 Cost	2006 Cost	2007 Cost	2008 Cost	2009 Cost	2010 Cost	2011 Cost	2012 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

Travel (weeks):	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Total Cost
													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	

6.3 Risk Register

Risk Exposure RE = Probability Score * (Cost Impact Score + Schedule Impact Score)

LOW	**RE < 10**
MEDIUM	**10 >= RE < 30**
HIGH	**30 >= RE <= 45**
VERY HIGH	**RE > 45**

Impact Score definitions

Cost Impact	Schedule Impact	Impact Score
<$50k	2-3 months	1
$50-100k	4-5 months	4
$100-250k	6-12 months	6
>$250k	>12 months	8

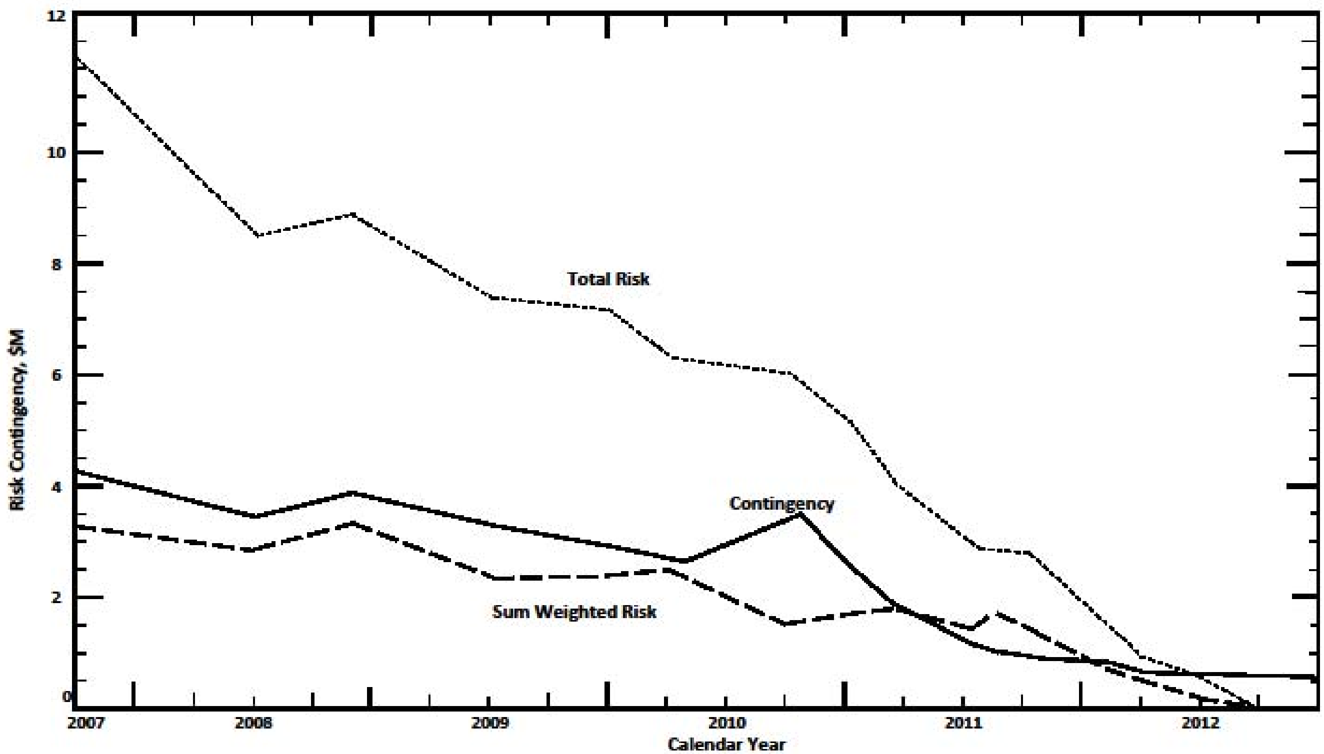
Probability Score

Impact level	Probability	Probability Score
Low	10%	1
Medium	20%	2
High	40%	3
Very High	80%	4

EVLA Project

Risk Register Summary

As of December 31, 2012



6.4 Remaining EVLA Project Funds Management Plan

The text in this section is taken directly from the Remaining EVLA Project Funds Management Plan, NRAO document number A23010N0008, Rev A.

INTRODUCTION

The remaining EVLA construction project funds are approximately $500k. It is assumed that NRAO will request a no-cost extension from NSF and that these funds will move to New Mexico Operations at the end of FY12. NM Ops will be required spend down these funds by the end of the second quarter of FY13. All risks associated directly with EVLA project construction have been retired, therefore the criteria for allocating these funds is to address new operational risks caused by the increased demand of the (E)VLA on the existing infrastructure. The items described in this document, which are in order of priority, are recommended for consideration.

ANTENNA CONTROL UNITS FOR TWO ANTENNAS - $104k

The aging VLA ACUs have been identified as a major threat to array reliability in a recent antenna lifetime. This topic was discussed at the December 2011 NSF EVLA Path to Completion review, and subsequently received broad support from the review panel to develop a prototype system. The 2012 User's and Visitor's Committee meetings echoed this support. Following the P2C review, $270k of EVLA funds were appropriated to develop a prototype system. If these additional funds are approved, a total of three antennas will be outfitted with new systems during the next 12 months. During the retrofit, components will be salvaged. This will provide a cache of spare components for the remaining old systems, relieving a sizable portion of the immediate risk. The $104k price tag includes the hardware to complete two retrofits ($30k each) and 0.5 FTE ($44k). A Critical Design Review is scheduled for November 2012, with the ordering of components to commence immediately afterwards. To assure adequate manpower support for the CDR and the subsequent hardware purchase, funding approval is requested for FY2013 Q1.

IMPROVEMENTS TO ELECTRICAL INFRASTRUCTURE - $100K

The VLA electrical infrastructure is not only aging, but is being subjected to far greater power requirements due to the EVLA upgrade. Constructed in the mid 1970's, it has become a concern for array reliability and staff safety.

$28k is requested for 2 new fused arm switches to replace the old units at DN9 and DE9 (The replacement switch for DW9 is already purchased). This will result in considerably less interruption and down time when power must be removed from an arm. At present, the entire site power must be shut down and the power line capped off upstream from the fault. The effort required to accomplish this is a considerable drain on resources and results in a significant loss in observing time. Additionally, the replacement of these switches will result in improved safety. The present fuses can fail shut, subjecting the technician to a hot circuit. The new switches will always fail open.

$72k is requested for six new 75KVA dead front oil filled transformers to replace existing units made with problematic Sierra style fuse holders. The older style transformers have been failing, most recently in December 2011 and then again in July 2012, resulting in several days of lost observing.

The improvements to the VLA electrical infrastructure described here are critical for the continued reliability of the array. Installation of the transformers and arm switches should happen as soon as the weather permits. For work to begin in early spring 2013, the purchase of the transformers and switches will have to take place not later than December 2012.

IMPROVEMENTS TO VLA BUILDING INFRASTRUCTURE - $95K

The aging infrastructure at the VLA site is no longer up to the standards of the original VLA. Under normal conditions such improvements would be handled by funds in NM Operations but there is a greater draw this year due to the transition from Construction to full Operations. One area that has shown an excessive amount of deterioration is the Control Building Annex. Crowded conditions exist for the Fiber Optic, Grounds, and Track crews which are housed in the building. Furthermore, the structure of the building is degrading to the point of severely cracked walls and foundations, a failing HVAC system, and rodent infestation. The human inhabitants of the annex need to be relocated to a better space, and the building needs to be removed.

Measures to move the Fiber Optic group to a more suitable lab in the Control Building are already underway. The newest building on site is the Cold Storage building, built to store equipment for the EVLA Project. $95k is requested to retrofit the Cold Storage building into a space suitable to house the Track and Grounds crews, as well as the HVAC team (presently situated in the Control Building). The $95k would be used to provide interior shop and office space, a restroom, septic tank and drain field, heating and cooling, lighting, and railroad track access to Cold Storage. Included also is $10k to pay for removing the Control Building Annex.

The spring and summer months are ideal for the VLA staff to perform the retrofit of the Cold Storage building. Therefore, material purchases should be completed by the end of FY2013 Q2.

ADDED STAFF TO COMPRESS SOLAR RETROFIT SCHEDULE - $176K - $352K

The components have already been purchased to allow for the upgrade of select EVLA receivers for the purpose of enhancing the solar observing capability. At present staffing levels and obligations, work to perform these upgrades will not be complete until the end of 2017. The addition of two temporary Front End technicians for two years each will allow for the work to be completed two years early (3Q 2015). The $352k cost includes two technicians for two years each, $88K per year per technician (fully loaded salary). For half of this amount ($176k) NM Operations could hire one technician for two years, which would result in a significant though less amount of schedule compression.

Everything is in place to perform this work with the exception of manpower. Additional staff to support this effort will be hired once funding is approved.

ADDITIONAL HARDWARE FOR ARCHIVE SERVER - $100K - $300K

$280k is already set aside in the project budget for archive hardware. This level of hardware (1 Pbyte) is suitable for anticipated data storage needs to the end of FY13.

One concern that we in Operations have is that Resident Shared Risk (RSRO) observing will require higher data rates than normal observing. We could mitigate this risk by setting limits on data rates at the cost of limiting the type of early RSRO science that gets done at on the VLA. Alternatively we could purchase an additional 1-2 Pbytes (including a mirror server). This is a low risk item since if the additional disk space is not needed in FY13, this expenditure would offset an expected draw on the FY14 operations budget. Purchase of this hardware would ideally take place by the end of FY2013 Q2.

SUMMARY TABLE

Item	Risk	Mitigation	Cost	Spending Profile	Notes
ACU	Downtime	Two more	$104k	FY2013 Q1	Can do >>2 with more $$
Electrical	Downtime	Replace	$100k	FY2013 Q1	Improves safety and reduces downtime
Buildings	Operations	Renovate	$95k	FY2013 Q2	One time Construction →Ops transition
Solar retrofit schedule	Delay in providing functionality	Additional staff	$352k	FY2013 Q1	Reduces schedule by 1-2 years
Archive	No disk space	1-2 PB more	$100-300k	FY2013 Q2	Purchase additional disk storage and review policy management

6.5 Lessons Learned

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Activity Schedule				
Consider that planning firm schedules for R&D activities is of limited value.	P	?	When designing a product that does not yet exist, it is often very difficult to predict when success will be achieved.	Planning schedules for production activities is very useful and these can be quite accurate. This is not always the case with R&D. Endeavor to be less critical and more supportive of design staff.
Communications Management				
Encourage face to face meetings among remote participants early in the project.	E	N	In the event various project staff are not located in the same proximity, communication inefficiencies sometimes exist until a time when the staff get to know one another.	Establish meetings early on where remote staff can establish agreements and form bonds.
Utilize short lines of communication	E	Y	With the exception of the HIA folks, all key people were in the building. And for the HIA exception, they were only a single time zone away. And, with the VLA site only 50 miles away, on-the-sky tests did not require any administrative overhead and very little time lost to travel. Having all people here at all times meant that ad hoc meetings, to deal with a sudden unexpected turn, were easy to arrange, and invariably resulted in a decision.	Strive to establish the shortest lines of communication possible.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
NRAO Directors and Assistant Directors respected autonomy of Project Managers	E	?	Occasionally it was noted in other projects (internal and external) that there was the appearance of micro-management from the top. This can result in a lot of time and worry expended in trying to provide/defeat/delay well-intentioned requests.	Assure autonomy of the PM.
Commissioning efforts by the core team tended to be very focused and when expertise was needed outside of the core group, there was confusion and difficulties shifting priorities in other groups to support commissioning. This in turn caused 'emergencies' as regular operations were interrupted.	P	N	To avoid confusion, miscommunication, and strained working relationships, we found that there must be daily contact and meetings at least 3 times a week to ensure issues between groups were solved and resources and priorities could be shifted to accommodate commissioning issues and high priority science operations. Second, the planning for new modes needed to take into account the fact that newly offered modes required continued support to work out "fiddly-bit" commissioning details that were not uncovered until the mode went "live". Thus, when releasing a set of new modes to the community, the planning needed to allow for a period of decreased new mode development in order to bring released modes into a final, robust state. Both of these aspects are critical to the continued sanity, enthusiasm and health of the commissioning team.	Have well-coordinated goals and schedules across the observatory that are agreed upon by all (electronics, software, operations, commissioning, user support and management).

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Project spread between Socorro and Penticton resulted in some scheduling problems.	?	N	The Penticton staff was operating under a finite timeframe. Therefore, the NRAO staff had to push to finish their tasks for which the contributions were vital well before the end of the project. We would have probably produced a better product had we concentrated more on the fundamentals of the correlator, and left some of the more extreme capabilities to be developed after the formal end of the project.	It may be there is no perfect solution to this kind of problem, other than to recognize that it will happen.
Regular weekly meetings	E	Y This had positive impact	Regular weekly team meetings (teleconferences) are very useful as a means to keep team members informed and to discuss current issues.	Plan for the weekly meetings. Make sure that all members of the team get a chance to talk about their work and raise issues as needed.
Periodical face-to-face meetings	E	Y This had positive impact	In the case of geographically dispersed team, periodical face-to-face meetings are necessary - they improve understanding and trust among team members. In the early stages of development EVLA correlator team had 2 face-to-face meetings per year - that worked well.	Allocate resources (time and funds) for regular face-to-face meetings. Plan face-to-face meetings well in advance so that time gets well used. For example, people can prepare presentations and reports to be discussed at the meeting.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Communicate clear time allocations and flexibility in scheduling to observers	P	N	At times we needed the capability to extend configurations to satisfy for some RSRO commitments.	Communicate to users from the onset that configuration dates are subject to change during project construction and commissioning.
Cost Management				
Bulk purchases of materials early in the project resulted in significant cost savings	E	Y	Materials such as steel, aluminum, and composite parts for the antennas were purchased in bulk early in the project, instead of on an antenna-by-antenna basis as had been done with VLBA. Having materials readily available kept the project moving. When purchasing in bulk, be care to consider if the design is likely to undergo future changes, or if the integrated circuits (FPGAs, digitizers) have been fully tested and reviewed for suitability.	Purchase in bulk quantities where practical, and encourage the use of identical common components where possible so as to increase order quantities and therefore reduce cost.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
HR Management				
Personnel retention planning was good during construction phase.	E	Y	Little or no turnover of key staff occurred during construction. The Project Scientist and Project Engineer were on board throughout. We did have three Project Managers, but all three were 'inside' people, already involved with the project, so the transition was easy. There were three Assistant Directors, and three Directors throughout the period -- but these changes had little effect on the project. A detailed personnel retention plan was developed, implemented, and observed. The plan was used by upper management to fund additional positions from NRAO operations funds. The plan was used as a model for the ALMA transition plan. Though the plan was successful, some staff that was hired for the construction project had term appointments. It would have been beneficial to retain some of the term limited staff.	Engage key staff so as to reduce likelihood of defections. Where practical, fill / backfill management positions from within the organization. Make provisions for, plan, and communicate that project and other development employees will be given opportunities to transition into operations.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Integration				
Establish formal Interface Control Documents (ICDs) between product groups and, where warranted, at interfaces within a group.	E	N	An agreed to listing of all aspects of an interface (signal name, type, mechanical and electrical specifications, etc.) will prevent misunderstandings and allow for a successful integration sooner. This was put into effect in a less formal way during this project, with good results.	Require design reviews where both entities take part. ICDs should be written and agreed to before the design is underway.
Establish an equipment calibration plan	P	?	Non calibrated or incorrectly calibrated equipment could cause problems and other delays within the project.	Insist on an equipment calibration plan, with checks, early in the project.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
A proper local test facility was not established at the onset	Both	Y	The prevailing thought was that the 50 mile separation between lab and site was of no consequence, so a proper test facility at the AOC was not built. This turned out to be a mistake. For the early part of the project, modules which worked in the lab failed at the site, and the needed people or equipment were 50 miles away. Much time was lost in shuttling. This issue went away once a proper facility was built in the AOC. The ALMA project took the opposite approach from the beginning. They built laboratory test racks that simulated the antennas and the central racks. Although EVLA could have done this also it was decided we would use antenna EA13 as the prototype. EA13 was out of the array for over 12 months but provided an excellent prototyping platform. The second antenna to be retrofitted went much more smoothly and was returned to the array within 4 months. The approach to install prototype hardware in EA13 successfully helped to quickly identify the inevitable problems which will be faced in the field. Ideal approach - construct a full system laboratory test facility, which would include a test correlator or at	Plan for and budget a systems test facility in the engineering lab to coincide with hardware integration.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
			least a correlator facsimile. But also strive to install hardware on an actual antenna as soon as practical (see "Prototype hardware installed on an antenna during early development").	

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Develop acceptance plans	E	Y	EVLA really didn't have formal acceptance plans for its major deliverables, although there was a test acceptance procedure for the retrofitted antennas. This was particularly acute for the correlator, where there was not a mutual understanding initially of what the 'end game' was. This unnecessarily led to angst and anxiety at DRAO and NRAO, and exacerbated budget planning for our Canadian colleagues	Develop acceptance plans which include a compliance matrix of performance and other criteria for major project deliverables. Include performance requirements which are derived down from scientific requirements. Allow for the possibility of waiver approval should certain criteria not be met.
Planning				
Prototype hardware installed on an antenna during early development	Both, but mostly E	N	The first EVLA project manager encouraged the engineering and testing staff to install prototype hardware into the array sooner rather than later. The engineering staff joked that the modules were installed in the array before the solder cooled. So, while there was a lot of time spent shuttling to and from the VLA in the early days, in the end this was a good policy because it started the dialog between the scientific staff and the engineering staff early in the project. This dialog kept the engineering staff aware of the scientific requirements and also helped the software developers understand the interface requirements.	Install prototype hardware on an antenna as soon as practical (but develop and make use of a lab test facility prior to antenna system integration).

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Conducting mechanical overhauls and electronics retrofits of the antennas in parallel, instead of in series, accelerated the project schedule.	E	Y	Early in the project, the mechanical overhaul of an antenna did not start until the electronics retrofit of the previous antenna was completed in the AAB. Thus, EVLA overhauls were originally done serially. The schedule was changed to move antennas to the master pad for electronics retrofits after the mechanical overhaul was completed in the AAB. This allowed the EVLA overhauls to be done in parallel	continue this practice
Improper balance of staff skills in the project.	P	Y	The project was mostly staffed with technical experts, and had a very limited number of people with programmatic skills. As a result, a number of organizational and managerial issues were not resolved in a timely way.	Strike the proper balance of technical and programmatic skill

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Original Front End budget was too light	P	Y	We skimped on the FE budget by reusing dewars and refrigerators. The reuse of dewars caused schedule problems, and the old refrigerators, particularly the Model 22s, were just worn out. A specific example that made no sense was to reuse Model 22s on X-band when the C- and Ku-band receivers were using Model 350s.	Scope the work element properly and give it sufficient budget to complete the work on schedule
Assign the most experienced team possible / Veteran staff	E	Y	Essentially all staff had a great deal of experience with the VLA, and their knowledge and expertise contributed to the successful completion of the project. Many of the key individuals were employed in the building for ten years or more prior to the start of the project. Implicitly, there existed a high level of trust amongst all key members.	Retain present staff and employ them in future projects. Take advantage of the local expertise and talent. Encourage project ownership.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Secure agreement on funding profile	E	Y	Early NSF funding of the EVLA project was not predictable and future funding was uncertain. NRAO management convinced NSF to commit to a specific funding profile, which allowed project management to make detailed project plans	Agree on a funding profile early in the project.
Proper technical expertise	E	Y	Assure technical challenges are identified and understood early in the project. Where we lack the technical expertise necessary to handle the tasks, hire the proper resources. We struggled with the wideband OMT designs initially. Steven Durand hired Gordon Coutts, who had the right skills and solved the problem quickly. Initially, this was a major risk to the project.	Hire staff with the proper skill to eliminate technical risk early in the project.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Shared risk observing	E	Y	Claire Chandler developed a shared risk observing program that made optimum scientific use of evolving EVLA capabilities. This was crucial for demonstrating project success and putting the new instrument under a full burden of testing to shake out any unanticipated issues. The success of the program gave us credibility and attracted new, young users to the instrument. The community scientists involved derived good orientation and understanding of the evolving system and felt invested in its success.	Demonstrate instrument capability as soon as practicable.
We needed to transition to science observing at night even while commissioning was progressing during the day.	E	Y	Bringing more complex observing modes on-line while observations were being scheduled each evening required a clear understanding of the priorities, well-coordinated development and testing by multiple teams (hardware, software & operations) and clear handover procedures between operations and commissioning teams. A small team of experts (3 people) coordinated the daily commissioning activities, headed by a single individual who understood the state of the system. There was enough expertise in the group to continue commissioning operations along different paths for up to several weeks at a time even if the lead commissioner was absent.	Keep at high priority the ability to commission during the day while observing science programs at night. This decreases time available for commissioning and science but it also ensures a more robust system since the system had to be tested for science each night.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
When a complex observing mode was first offered, it was not perfect and there was an element of risk that needed to be addressed. Both the user and NRAO had to accept this risk level when observing in that mode (e.g., there were likely some work-a rounds or other non-optimal ease-of-use issues).	E	N (There is no proof that the project end date was affected by this process but the final modes that were delivered were more robust, more comprehensive and better documented because of this strategy)	Modes were first put out to a limited and expert user group made up of the RSRO scientists working closely with the commissioning team. The value of this strategy was that complicated observing modes were offered in a step-wise fashion, minimizing the risk of end-user acceptance when the mode was released (because outside scientists were involved in the early development process). It also engaged the user community in the commissioning process and then used their input as guidance for how to bring the mode to full, robust operations.	Develop well-defined commissioning 'paths' in which commissioned observing modes are offered first as RSRO, then as shared risk, and then as a general observing mode with fully supported documentation.
Continued observing during early phases of EVLA construction	E	?	Although it was expensive in both dollars and manpower to make the systems compatible, it gave us not only a couple of years of good VLA science, but also let us check out the antenna based electronics (LO IF system and data transmission system) in a system that we understood very well. It was also important for the early stages of software development for both the MIBs and for the Executor. And it meant that our scientific expertise in the use of the instrument did not decline from lack of use.	Strongly consider maintaining a regular observing schedule when upgrading an instrument.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Schedule to achieve minimal capabilities of correlator was too optimistic.	?	N	A one month observing shutdown during the switchover to the new correlator was originally scheduled, and this was later extended to two months. We were overly optimistic because we had already tested the correlator system in a reduced configuration, and underestimated the difference that having the whole system in final or semi-final state would make.	The lesson is never to underestimate the time required to bring a complicated system into operation; in particular there will be a significant interval in which all the pieces of the system work, but the system as a whole does not. Scheduling four months for the switchover to the new correlator would have allowed sufficient time to bring the system online in a more stable state.
Allocate enough time for unit and integration testing	E	Y	Well planned and extensive testing of all sub-systems during system integration time is essential - uncovered issues and bugs can be more efficiently corrected while the whole team is still focused on the project. Problems uncovered later, when the development team is dissolved and developers move on to other projects, may require several times more time to troubleshoot and solve.	Allocate resources (time, equipment, and people) for unit testing and integration testing. Advocate for and represent interests of the development team to management.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Complete system integration to the greatest extent practical prior to onset of commissioning.	E	?	Endeavor to avoid doing system integration during commissioning, but recognizing that some will be necessary, have the skills and resources on hand to perform system integration. Establish and maintain communication / staff bridges between science and engineering throughout commissioning.	Create measureable go/no-go requirements prior to the onset of commissioning.
Project Management				
Develop reporting metrics that are meaningful to stakeholders	E	Y	There was a debate on whether the EVLA should use Earned Value as a reporting metric. We decided this would not be useful for our stakeholders (NSF, users, management), and elected to report on items that had meaning to them, such as percentage contingency and number of antennas outfitted as functions of time. Reporting this information gave us credibility with our stakeholders, helped them understand status, and led them to advocate for us.	Establish and report project metrics that are meaningful to stakeholders.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Activate lessons learned process early in the project. Encourage regular feedback.	E	N	We started the LL work far too late and risked missing key data as people had already moved on from the project.	Have a system in place at the time the project is approved to assure feedback part of the team ethos. Publish the data regularly; assure anonymity. Keep the system simple to encourage participation.
Allocate resources at the onset for the establishment of a systems group at the beginning of the project	E	N	The EVLA project relied heavily on a single Systems Engineer to assure technical cohesiveness and consistency. This task is simply too much for one person to shoulder, especially given that this individual also was called upon to serve as Project Engineer.	A Project Engineer and systems group are needed early in the project and this should be funded in the project proposal. A small but dedicated group assigned to the establishment of interfaces and standards as well as the facilitation of documentation should be established early on. Budget such that an engineer from the Systems Group can be assigned to each product area. If no budget exists to dedicate staff for a systems group, consider assigning one member of each product area to interface directly with the Systems Engineer.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Establish clear procedures for issue solving so as to not allow for unanswered questions to delay any aspect of the project.	E	Y	EVLA decision making was a streamlined process which allowed for timely verdicts. This greatly facilitated the successful and on time completion of the project.	For future projects, insist group leaders have ultimate decision making authority for their groups. No 50/50 sharing of responsibilities.
Couple risk management and change control with contingency usage	E	Y	Percent project contingency was very low at mid-project, and de-scope options were developed. A risk management plan was developed and implemented so that contingency usage was a transparent process that showed how risk was mitigated or minimized. All change control meetings reviewed risk register and contingency status before change requests were approved. This helped with project cost control.	Couple risk management with contingency usage and administer through a Change Control Board.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Establish a change control board early on in the project	E	Y	In the first year of the project the EVLA change board was established. The board included the Project Scientist, the Project engineer, Project manager, the head of EVLA computing, the head of the WIDAR team and the NMOPs Director. All changes to the budget, schedule, or the project book specifications needed to obtain change board approval. Although the change board was casual in the beginning, as the project progressed, the change board became more formal and was the vehicle which was used to shape the final EVLA. Change board items could be passed with a majority vote but the overwhelming majority were passed with a unanimous vote. This was accomplished by the change board staff and the engineering staff thoroughly discussing the issues before each vote. These discussions are what made the change board a successful and valuable tool.	Establish a change control board early on in the project.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
WBS was developed and routinely maintained	E	Y	Despite initial resistance, a project WBS was developed. It was updated by group leaders and project management every 6 months thereafter. The updates provided common understanding of the budget and were a major factor in completing the project on budget	Establish and maintain a detailed WBS.
Leadership of work elements	E	Y	The technical and programmatic oversight in the Front End group was originally assigned to one person. This turned out to be too much of a burden for one person given the number and magnitude of the technical and programmatic issues that required resolution. The FE work got into schedule and budget problems as a result. Progress was eventually made after the responsibilities for programmatic and technical issues were assigned to separate individuals. This wasn't required in all groups (e.g antenna, LO, DTS)	Evaluate programmatic and technical scope within a work element, and assign responsibly of each to separate people if warranted. Where a personnel void exists, fill it early in the project.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Authority, responsibility and ownership for a work element	E	Y	Giving responsibility and appropriate authority to a person leads to ownership and is paramount to success. Some good examples of this were Tom Baldwin on fiber optic design and installation, and Michael Rupen on correlator commissioning.	Empower staff
Unified Project Management Control System	E	Y	Identify, detail, and track critical tasks and their dependencies early in the project. Establish reporting practices across all locations so that critical items which require extra resources can be identified well before they pose a problem for the schedule. Include all aspects of the project in the unified schedule/plan (design, integration, production, commissioning...). To support plan, communicate clear responsibilities to the various groups.	Early in the project, implement a consistent project management control and reporting system which is agreed to and followed by all project entities and enforced by the Project Manager.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Project Maturity was lacking in many leadership roles at the outset of the project. No set expectations on protocols were established which allowed for self-interpretation of how to manage a project.	P	Y & N	Projects leaders were first technical experts, without much project management skills. Most attention was placed on technical measurement which created a number of issues. Most evident was the lack of knowledge of procurement control and monitoring progress. Too much time was spent on procurement activity that others were assigned to do. Circumvention of procurement protocols happened often which resulted in undesirable results at times. Fortunately for the project most of these occurrences' happened under the <$10k cap. The project leaders just weren't good at tracking the differences between what was planned and what was actually happening. There was too much time spent on self-gratifying items than on focusing on the many details that were more problematic. This happened more in the area of system engineering.	Set clear expectations of responsibilities. At the most fundamental level, leaders need to know where to spend most of their time and what to delegate to others. And how to track progress and manage the work priorities. Institutional standards would be most useful to have in place as guidelines for project leaders to follow. Such guidelines would better clarify these responsibilities and help to apply focus on what really matters on the project. Those chosen to lead projects in the future could benefit from short review tutorials of managing projects beforehand.
Establish and enforce software/firmware configuration management	?	?	Our initial philosophy regarding software and firmware versions was "there is no back, only forward." In practice, this proved unrealistic. Versioning of software is vital, versioning of firmware is critical. Multiple FPGA personalities exist in the system, and some are very problematic.	Establish and maintain software and firmware configuration control.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Scope Management				
Early RSRO visitor involvement produced a heavy load on the core commissioning team since they had to coordinate RSRO observations as well as verifying and troubleshooting basic functionality.	P	N (but it stressed out the commissioning team and could have caused a melt-down if it had not been dealt with)	Our goal was to bring in visiting scientists with extensive and clear expertise to help with commissioning. We had also planned to engage the community through this RSRO program but visiting scientists were not always contributing effectively to the commissioning process and the overhead to direct them was a drain on the core commissioning team. Early RSRO involvement was a difficult time to get through and required balancing RSRO activities with a high level of expertise in the RSRO visitors themselves to help commission (not everyone provided good RSRO input). To solve the problem, RSRO visitors required highly focused priorities that matched their interests with EVLA commissioning needs. Having internal contacts assigned to them also helped them contribute effectively and ramp up quickly. It was also imperative that RSRO visitors were assigned short-term projects that could be completed in 3 months or handed over effectively to the next RSRO. The bottom line is that the RSRO program had to be very actively managed or these short term resources became a drain on the commissioning effort, diverting the	Don't usually bring in senior scientists to help with commissioning - they often have too many other commitments to contribute effectively. Rather, focus on bringing in enthusiastic post-docs for a minimum of 3 months at a time (but not too many at once). Give them clear goals, priorities and contacts to work with. Using RSRO visitors to help write user documentation was particularly useful because it allows them to learn more about the system (which they find rewarding) and it frees up the commissioning team to focus on technical commissioning.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
			commissioning path into so many avenues that it was difficult to see the critical path.	

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Define detailed requirements as early as possible.	E	Y	Too often requirements for software systems were not defined in advance but on-the-go. Such approach slows down development process, often requires re-work of previously implemented software and results in sub-optimal architecture.	Definition of requirements, as well as, development and review of related documents should be planned from the beginning and resources should be allocated appropriately (software developers, astronomers, and system engineers).
Define the minimum set of documents and formal review process.	E	Y	Especially important during early stages as it forces participants to thoroughly and systematically consider ideas, requirements, technologies and concepts; fosters discussion and allows participants to learn from each other. Investment in documentation pays off, as it speeds up learning process for developers and testers who join the project late(r).	Allocate time and resources for development of documents and formal reviews.
Establish a clear set of priorities and milestones to be achieved during commissioning.	E	?	A set of commissioning goals with their relative priorities (re-visited weekly) helped to keep staff focused on verifying array performance.	Create commissioning milestones, set priorities, review weekly.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Technical				
All module and subsystem communication over optical Ethernet.	E	N	The EVLA project made the decision early in the project that all module and subsystem communication would use optical Ethernet. It was a good decision to use a communication industry standard with the addition of the optical component. From a hardware point of view Optical Ethernet was a good decision because it was straight forward to move the optical signal in and out of the RFI tight modules using a RFI tight optical connector. The EVLA project chose a FC connector made of metal.	Design using optical interfaces (instead of copper).
Use the same style assembly to interface all modules to the greater system.	Both	N	The plan was every module would use the same Module Interface Board, (MIB). The design and manufacture of these MIBs took 24 months. During this period module developers were without a method to communicate with their prototype boards using Ethernet and/or optical Ethernet. This delayed EVLA project development by at least 14 months, but the overall project end date did not suffer. Some method to poke and peek should have been developed early in the project to support the LO/IF module development.	A powerful Module Interface Board is a good idea, but an allowance must be made for temporary communication to the assemblies while this assembly is being developed.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Module Interface Board (MIB) lacked some features	P	N	The use of a common MIB board was a great idea. The MIBs were basically a digital I/O board but each module developer also needed to sample analog signals. The first engineer to develop an analog interface board basically defined the standard. But this de facto standard needed to be enhanced as other requirements were added. The end result was a collection of analog boards that were compatible with the MIBs but each a little different.	In this case, this problem may have been unavoidable. However, it serves as a reminder to endeavor to conduct rigorous design reviews before committing to a design.

Observation or Comment	To be Encouraged (E) or Problem to Avoided (P)?	Project End Date Affected?	Narrative	Suggested Action
Aggressively solicit expert advice, external if necessary, when pushing technologies to their limits	E	Y	When there are choices that involve pushing technologies to their limits, possibly even just some doubts about feasibility, then it would be wise to solicit expert advice (either internal or external) possibly via a review, whichever is most appropriate. An example is that of the 3-bit sampler. The selected device was properly reviewed prior to purchase, however our application of using the device in a broadband noise environment was not familiar to the manufacturer. As a result, test data provided with the sampler chips was not completely relevant to project needs. Much time was spent, and an associated delay in schedule resulted, by NRAO staff having to fully characterize the 3-bit A/D. This did not result in a delay to the end of construction date, but certain system testing commissioning tasks were affected.	Take extra care when reviewing bleeding edge technologies.