NRAO Response to NSF's EVLA Site Visit Panel Report

31 Jan 2001

P. Napier EVLA Project Manager
R. Perley EVLA Project Scientist

Introduction

In May 2000, the NRAO submitted to the NSF a proposal to fund the first phase of the Expanded Very Large Array Project. On December 14 and 15, 2000, an NSF panel met in Socorro to review the proposal. The panel submitted its report to the NSF in January, 2001. Included in the report were a number of requests to the NRAO for expansion on, and clarification of aspects of the proposal which were presented verbally to the committee, but which were not in the earlier submitted proposal. This document contains this requested information.

The NSF request came to us in the form of nine specific questions, which we have included as an appendix to this report with annotated comments giving the location in this report where the answers will be found. Rather than respond to each in turn, and noting that most of the questions are in the areas of management and computing, this response has been organized under three major headers:

- Management Issues
- Scientific Issues
- Technical Issues

We have also taken the opportunity to include material which was of interest to the Site Visit Committee, but which did not appear in the formal request for information.

EVLA MANAGEMENT PLANS

1 Organizational Responsibilities

The relationship between the EVLA Project and the other operational units and projects at NRAO is indicated in the proposed NRAO organization chart shown in Figure 1. This shows that two NRAO groups important to the EVLA Project, the NRAO Data Management Group and the ALMA Project, have their own management structure. The EVLA Project will be managed by a Project Manager reporting to the Assistant Director for Socorro Operations. The manpower resources required to accomplish the EVLA tasks will be supplied by the existing Socorro Divisions with new positions added to these Divisions as necessary.

The EVLA Project organization is shown in more detail in Figure 3 which shows a matrix management structure in which the Socorro Electronics Division, Socorro Engineering Services Division , Socorro Computing Division, Socorro Business Division and Socorro Scientific Staff provide services to both the EVLA Project , managed by the EVLA Project Manager, and to VLA/VLBA Operations managed by the two Deputy Assistant Directors. Some EVLA software tasks, defined below in Section 3.2, will be performed by the NRAO Data Management Group as contracts to the EVLA Project. These contracts will be managed for the EVLA by the Socorro Computing Division Head. The activities of the Canadian and Mexican partners will be coordinated by the EVLA Project Manager. The responsibilities of the key positions in Figure 2 associated with the EVLA Project are summarized below. The name of the person currently planned to occupy the position is also given. The resumes of these people are included in the Appendix.

EVLA Project Manager (P. Napier)
Overall responsibility for accomplishing the EVLA Project on budget and on time with all performance requirements achieved. This will be accomplished using the management tools discussed below. An assistant will provide the effort required to implement and update these management tools on a monthly basis.

EVLA Project Scientist (R. Perley)
Responsible for communicating with the scientific community, both inside and outside NRAO, to ensure that the performance requirements for the EVLA match the community's priorities and maximize the scientific capabilities achievable with the available budget.

EVLA Electronics Systems Engineer (J. Jackson)
Responsible for overview of the EVLA electronics system to ensure that the interfaces between all electronic subsystems are correct and that the design will ensure that all performance requirements will be met. Works closely with the EVLA Software Systems Engineer to ensure that all interfaces between hardware and software are correct.

EVLA Software Systems Engineer (TBD)
Responsible for overview of the EVLA software system to ensure that the interfaces between all software subsystems are correct and that the design will ensure that all performance requirements will be met. Works closely with the EVLA Electronics Systems Engineer to ensure that all interfaces between hardware and software are correct.

Socorro Electronics Division Head (C. Janes)
Responsible for the production of the Feed, Receiver, Local Oscillator, Intermediate Frequency and Data Transmission Subsystems required for the EVLA.

Socorro Engineering Services Division Head (L. Serna)
Responsible for all modifications to the VLA antennas required for the EVLA.

Socorro Scientific Staff Head (J. Ulvestad)
Responsible for all scientific studies required to set performance requirements for all hardware and software subsystems, and for all astronomical tests required for system commissioning and specification verification.

Socorro Computing Division Head (G. van Moorsel)
Responsible for ensuring that software and computing hardware required for the EVLA is provided on schedule and budget. Supervise the Manager of the EVLA Control and Monitor Software group. Manage those software packages produced by the NRAO Data Management Division as contracts to the EVLA Project.

Socorro Business Division Head (S. Lagoyda)
Responsible for the preparation of the monthly Project Financial Statement and for all procurement activities required for the EVLA.

Canadian Partner Correlator Project Manager (P. Dewdney)
Responsible for the design and construction of the WIDAR correlator as the contribution of the Canadian Partner to the EVLA Project.

Mexican Partner Project Manager (L. Rodriguez)
Responsible for managing those components that are produced in Mexico as part of the contribution of the Mexican Partner to the EVLA Project, and for sending to the EVLA Project any remaining funds from the Mexican contribution.

NRAO Associate Director for Data Management (T. Cornwell)
Responsible for the coordination of all Data Management software projects within NRAO. Manages the activities of the NRAO Data Management (DM) Group. Those EVLA software packages that are similar to packages already being written by the DM Group will be provided by the DM Group as contracts to the EVLA Project.

1.2 Project Oversight and Advice

Oversight of the EVLA Project will occur at a number of levels:

AUI Board of Trustees
The Board will receive periodic reports from the Project Manager on the status of the Project and the NRAO Visiting Committee, which reviews the whole of NRAO for the Board, will review the status of the project at the annual Visiting Committee meetings.

NRAO EVLA Advisory Committee
An advisory committee consisting of experienced scientists from outside of NRAO will advise the NRAO Director on the scientific and technical priorities of the Project. Membership will include representation from the partner countries. This committee will be convened by the Project Scientist and chaired by one of its members and will meet once or twice a year. An important function of this committee will be oversight of the software aspects of the EVLA Project, so committee members will be chosen to provide expertise with astronomical software systems.

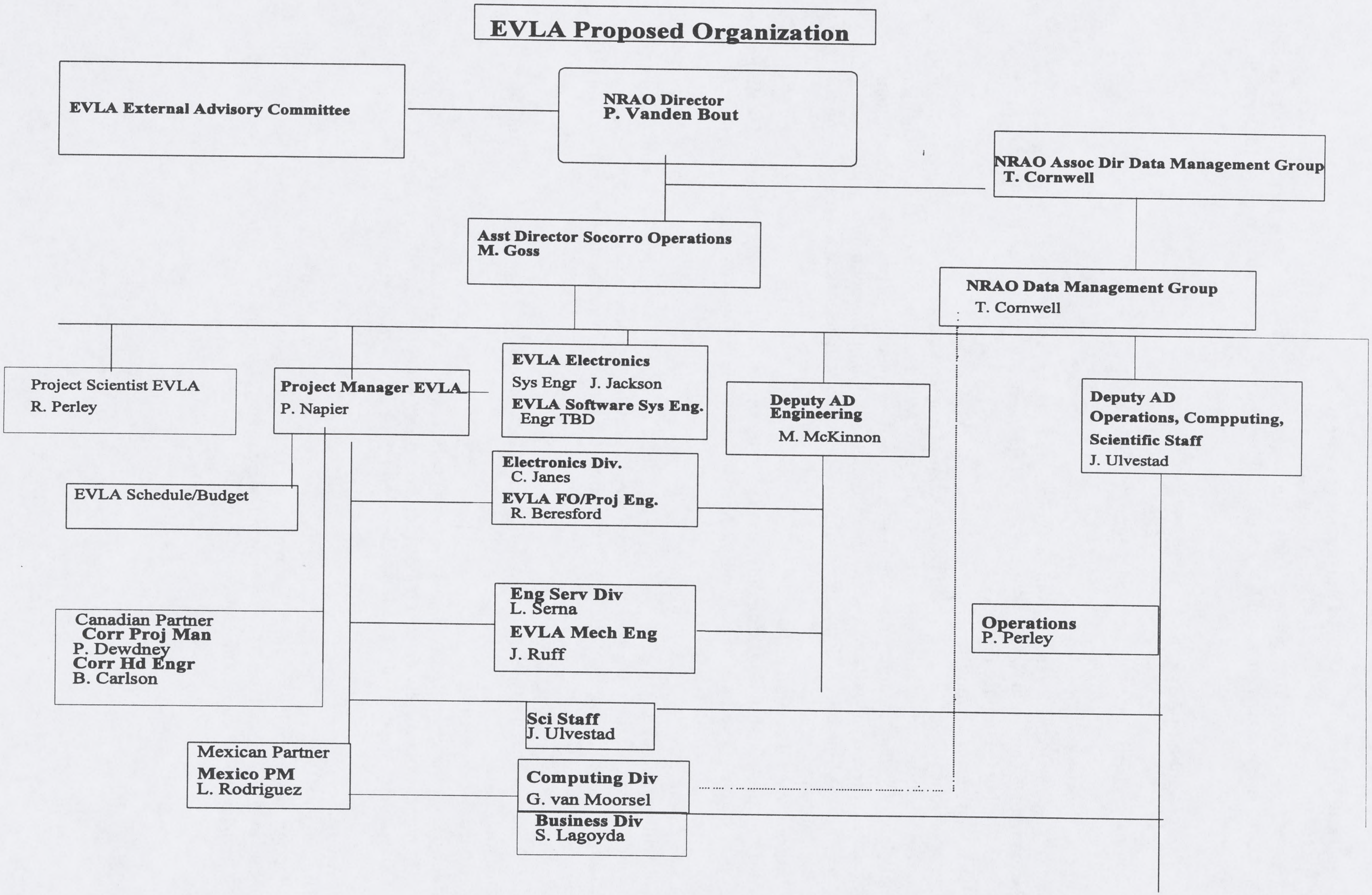
NRAO Program Advisory Committee
The NRAO Program Advisory Committee advises the NRAO Director on the status and future planning for all NRAO projects and operational units. The EVLA will be reviewed by this committee at each of its annual meetings.

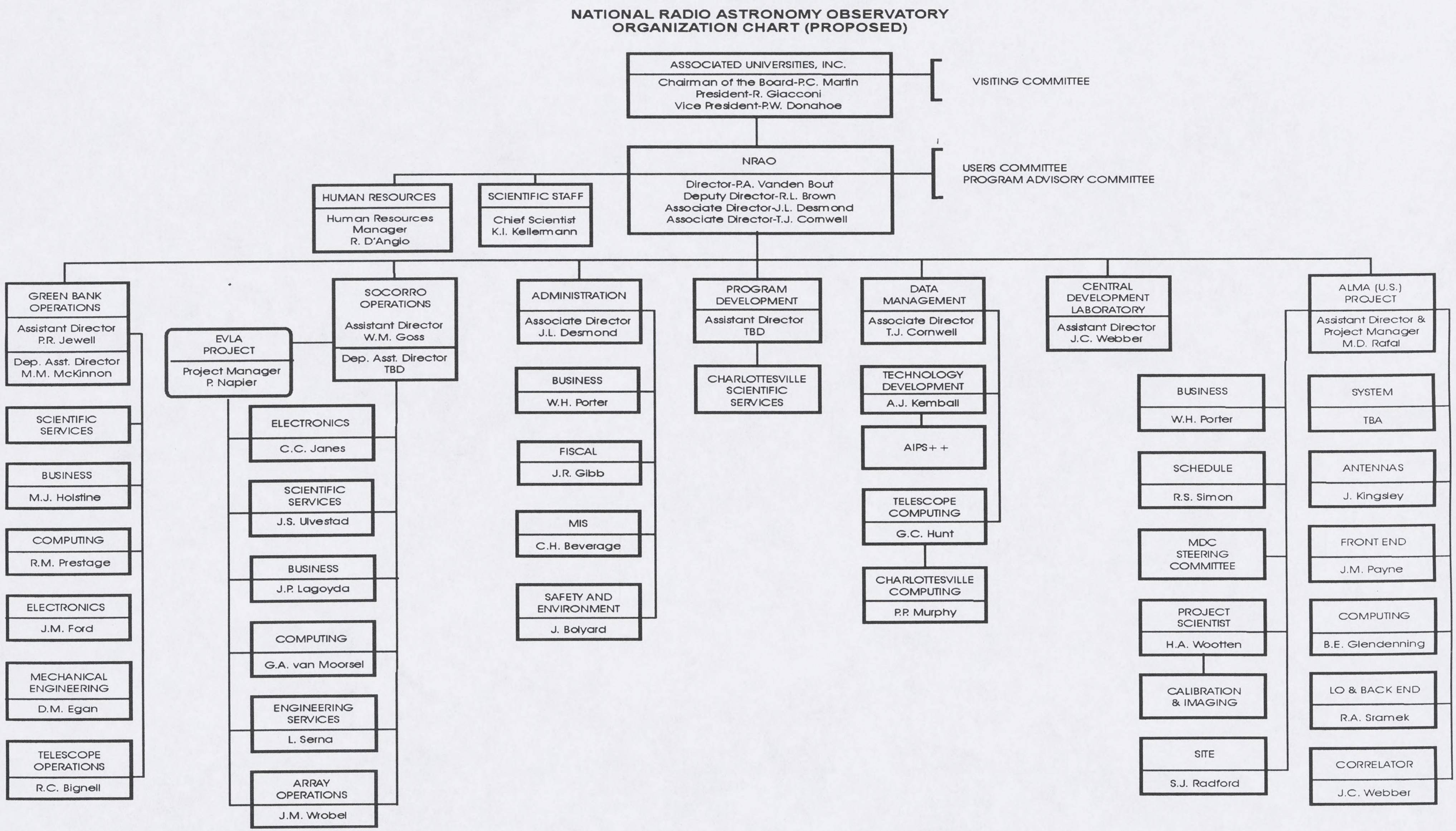
NRAO Users Committee
The EVLA will be reviewed by the NRAO Users Committee at its annual meeting. This review will be an important mechanism for the astronomical community to provide comment to the Project concerning the EVLA performance requirements and the plan for keeping the VLA in operation during the transition to the full EVLA.

Reports to the NSF
The Project Manager will provide written monthly reports to the NSF giving the technical and financial status of the project.

Internal Advisory Committee
A committee of experienced NRAO scientists and engineers from outside the Project will provide advice to the Project Manager and Project Scientist concerning priorities and decisions. Membership will include the partner organizations. The committee will be convened by the Project Manager and chaired by one of its members

Design Reviews
Preliminary and Critical design reviews will be conducted for all hardware and software subsystems under NRAO's Design Review rules which will provide a correct balance of Project and External review. The reports of the reviews will be given to the reviewing bodies listed above and it will be the responsibility of the Project Manager to act on the findings of the reviews.


EVLA Proposed Organization
EVLA External Advisory Committee
NRAO Director
P. Vanden Bout
NRAO Assoc Dir Data Management Group
T. Cornwell
Asst Director Socorro Operations
M. Goss
NRAO Data Management Group
T. Cornwell
Project Scientist EVLA
R. Perley
Project Manager EVLA
P. Napier
EVLA Electronics
Sys Engr J. Jackson
EVLA Software Sys Eng.
Engr TBD
Deputy AD
Engineering
M. McKinnon
Deputy AD
Operations, Compputing,
Scientific Staff
J. Ulvestad
EVLA Schedule/Budget
Electronics Div.
C. Janes
EVLA FO/Proj Eng.
R. Beresford
Canadian Partner
Corr Proj Man
P. Dewdney
Corr Hd Engr
B. Carlson
Eng Serv Div
L. Serna
EVLA Mech Eng
J. Ruff
Operations
P. Perley
Sci Staff
J. Ulvestad
Mexican Partner
Mexico PM
L. Rodriguez
Computing Div
G. van Moorsel
Business Div
S. Lagoyda



igure 2. Proposed NRAO Organization Chart

1.3 Management Tools

The management of the EVLA Project will be less complex than the management of the ALMA Project because of the smaller size of the project, because the bulk of the project will be performed primarily by an existing group of co-located people and because of the reduced role of the international partners in the EVLA compared to ALMA. Nevertheless, the EVLA is sufficiently complex and of an extended duration so that the use of modern project management tools is required. The EVLA Project will use the same management methodology introduced to NRAO by the ALMA Project. This includes:

Work Breakdown Structure
- Definitions of Systems and Sub-systems
- Tasks & Dependencies
- Schedule
- Budget
- Personnel and other Resources

Change Control Board

Design and Performance Specifications
- Interfaces
- Contingency Allocation - Cost / Schedule

Document Control
- Project Book (details of work plan)
- Specification Documents
- Interface Control Documents
- Drawings: Approval, Archiving, Revisions

Project Monitoring
- PDR, CDR
- Periodic Reporting
- Milestone Tracking
- Earned Value & Percent Complete Analysis

Weekly Division Head Meeting

A weekly meeting of the managers of the project, at and above the level of Division Head, to review progress, set goals and solve problems on a short term basis.

1.4 Schedule

The current principal milestones for the EVLA Project are:

Milestones	Date after start of funding
Project Management Plan	3 mos
System PDR	6 mos
LO / IF / FO PDR	6 mos
Feed Cone PDR	6 mos
Rcvr Feed PDR	6 mos
On-line Computing PDR	9 mos
System CDR	1 yr 6 mos
LO / IF / FO CDR	1 yr 6 mos
Correlator PDR	1 yr 6 mos

'eed Cone CDR	1 yr 8 mos
₹cvr Feed CDR	1 yr 8 mos
)n-line Computing PDR	1 yr 8 mos
start LO/IF/FO Installation	1 yr 11 mos
start Feed Cone Installation	2 yr 3 mos
'orrelator CDR	3 yr 0 mos
tart Correlator part purchase	3 yr 2 mos
tart Rcvr Installation	3 yr 8 mos
love Correlator to VLA	4 yr 6 mos
)n-line Computing, ready for archive	4 yr 10 mos
egin Correlator test observing	5 yr 6 mos
'orrelator Operational	6 yr 0 mos
inish LO/IF/FO Installation	6 yr 12 mos
inish Rcvr Installation	8 yr 10 mos
VLA Operational	9 yr 0 mos

.5 Budget

The budget for the EVLA Project, presented in the Proposal, was developed by NRAO personnel using their previous xperience with the VLA and VLBA construction projects and the ALMA Design and Development Project. Bottom-up costing was one using a Level 3 WBS in most cases and a Level 4 WBS for systems that are particularly well defined, such as the receivers. A evel 3 WBS means that cost estimating was done at the module level and an example of this is shown in Table 2 which shows the ost estimation for the Local Oscillator System. A Level 4 WBS means that costing was done at the component-within-the-module vel. An example of this is shown in Table3 which shows the cost estimation data for the electronics components for the 22 GHz eceiver. Estimates for parts costs and personnel hours for assembly, test and installation have been included for all subsystems. RAO's standard rates for the various personnel categories such as scientist, engineer, technical specialist and technician were used calculate salary costs from the estimates of personnel hours. NRAO's standard personnel benefit rate was used for calculating ersonnel benefit costs. Contingency was estimated based on the risk level of the individual subsystems, giving an average contingency r the project as a whole of 15%. Contingency will be held by the Project Manager and will be allocated as needed based on Change oard recommendations.

able 1 Example of Sub-System Cost Analysis for the EVLA LO System

Example of Sub-System Cost								
WBS	**Materials & Services**					**Wages**		
	Quant	$/unit	Cost	FTE	FTE	$/FTE	$/unit	Wages
		($k)	($k)	/unit		($k)	($k)	($k)
6 Local Oscillator System								
H-maser & Rb Frequency	1	300	300					
LO Ref Generator	1	15	15	0.06	0.1	30	1.8	2
LO Ref Distributor - Control Bldg	1	5	5	0.06	0.1	30	1.8	2
Microwave Round-trip Phase	30	15	450	0.08	2.4	30	2.4	72
LO Ref Distributor - Antenna	30	5	150	0.04	1.2	30	1.2	36
Power supply module	30	5	150	0.04	1.2	30	1.2	36
Engineer Supervisor, testing:					5.0	65		325
					4.5	45		203
Assemble and Test - Bins and	60	1.5	90		6.0	65		390
					5.5	30		165
NR Engineering Design LO (3 x	1	50	50		2.0	65		130
					2.0	45		90
					2.0	30		60

		Work-Months						
Local Oscillator System	**FTE**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**

Lead Eng, Design Production &	Eng	7.0	12	12.0	12	12	12	12	12
Module production & test, Lead	TS II	6.5	6	12.0	12	12	12	12	12
	Tech	16.5		18.0	36	36	36	36	36
Assemble, sys test bins & racks	Eng	6.0		12.0	12	12	12	12	12
Assemble, sys test bins & racks	Tech	5.5		6.0	12	12	12	12	12
		41.5							

Table 2 Example of Cost Estimate Data for EVLA 22 GHz Receiver

	VLA 22 GHz Rcvr Parts List		Revised 2000-Sep-28		
	49101.7655.80122				
				Qua	Cost
Item	Component	Mfg	Model/Drawing #	Sys	ea
1	Cooled isolator	PAMTECH	KYG2121-K2	2	$1,900
2	Cal splitter	Krytar	6020265	2	$495
3	WG to SMA adapter	MDL	WR-42 TO SMA	5	$78
4	SMA dewar feedthur	MA-COM	2084-1100-00	3	$37
5	RF Bandpass filter	K&L	13FV10-22250/U8500-O/O	2	$715
6	Post Amp	MITEQ	JS4-18002650-25-8P	2	$1,600
7	Mixer	MITEQ	TB0426LW1	2	$500
8	LO splitter	MAC TECH	PA8207-2H	1	$107
9	IF Filter	K&L	4B380-4750/795-OP/O	2	$185
10	IF isolator	DORADO	31CP51-1	2	$301
11	LO isolator	DITOM	DF2806	1	$165
12	LO amp	MITEQ	JS2-13502150-90-16P	1	$975
13	Cal Atten	NRAO spares		2	$0
14	Noise Diode	NOISE/COM	NC5242	1	$1,710
15	Solar cal amp	MITEQ	JS2-18002650-50-3P	0	$1,145
16	Cal coupler	NRAO	See Dwg lisr	2	
17	WG termation	Microwave Filter Co.	C2T2100	2	$25
18	WR-42 H-plane Bends	AMC	HB4200M1	2	$50
19	WR-42 E-plane Bends	AMC	EB4200M1	1	$50
20	Coax 0.141	Precison Tube	AA50141	8	3/'
21	Coax 0.085	Precison Tube	AA50085	20	5/'
22	SS Coax 0.085	Precison Tube	BS50085	8'	11/'
23	Card Cage	AOC		1	$130
24	Misc			1	$200
25	Misc EPOXY KITS	ARMSTRONG	K50618	1	$17
26	Misc INDIUM SHEETS	METAL SPECIALTIES	6"X12"X0.005" 99.99%PURE	1	$163
27	WR-42 cover flanges	PEM Machine	UG595/U	2	$10
28	WR-42 choke flanges	PEM Machine	UG596A/U	2	$10
29	SMA Connector 0.140	M/A COM	2001-5031-02	10	$10
30	SMA Connector 0.085	M/A COM	2001-5032-02	30	$10
31	½" Brass nipple	AIBUQ VALVE	1/2" pipe 3" long m2m B-8-HLN-3.0	1	$2
32	Brass fitttings elbow	AIBUQ VALVE	1/2" pipe 90 deg street-L male to female	1	$2
33	Brass fitttings elbow	AIBUQ VALVE	1/8" 90 deg street elbow MFB2SE	1	$2
34	½" Brass nipple	AIBUQ VALVE	1/2" pipe 2" long m2m B-8-HLN-2.0	2	$2
35	Valve, manual	AIBUQ VALVE	1/8" pipe swagelock B-2P4T2	1	$5
36	Vacuum flange	Scientific Sales	KSF-0416-1	1	$15
37	Cryo lines	Anamet	2-4',2-7',1/2" ID	2	$143
38	Modification dog house	AOC/E&S		1	$0
39	Dewar	AOC		1	$700
40	CTI Model 350 Refg	CTI	MODEL 350		
41	Dewar Vacuum Sensor	Teledyne	DV-6R VACUUM TUBES #55-38R		
42	ASCO Vave	G THOMPSON OR SMITH	8030R17VH	1	
43	Pump Vacuum Sensor	Teledyne	DV-6R VACUUM TUBES #55-38R	1	$60
44	50K Sensor	LAKESHORE	DT-471-DI	1	$143
45	15K Sensor	LAKESHORE	DT-471-DI	1	$143

46	Therm Cutout	Elmwood Controls	3450-87-315-L140 96/50	1	$15
47	Heater	Hotwatt	SC252.25	1	$25
48	LNA Bais Conn, u-min "D" feml	ITT Cannon M83513/02-BN	FP12S-1	2	$10
49	Bais Connector	ITT CANNON	KPT01H18-32P	1	$169
50	Bais Connector	ITT CANNON	MS3116F18-32S	1	$20
51	Cryo refig connector female	DEUTSCH	DM9702-3S	2	$104
52	Cryo refig connector male	DEUTSCH	DM9702-3P	2	$104
53	F14 Module	AOC	DCS	1	$2,380
54	F14 Wirewrap	AOC	DCS	1	$400
55	RF Tight box	Compac	S58010-175-1	1	$180
56	RF Tight Gasket	Compac	SRF Gasket	4'	$5

1.6 Procurement Plan

The EVLA and NRAO groups responsible for providing the various EVLA subsystems are identified in Section 3.2 above. All software subsystems will be written by software engineers working in either the Socorro Computing Division or the NRAO Data Management Group, although it is likely that several of these NRAO-written programs will have imbedded in them particular commercial software packages.

All mechanical and electronics subsystems will be supplied by the Socorro engineering divisions who will utilize, to the maximum extent possible, commercial machine shops, printed circuit board fabricators and electronic sub-assembly houses. With the current high demand within the communications industry for RF, fiber optic and high speed digital equipment the rapid procurement of these types of components has been difficult. It is possible that these problems will ease in the future if the US economy continues to slow down, but in any case the key to solving procurement issues of this kind is careful advanced procurement planning. It should be noted that the routine production phase of most of the electronic subsystems for the EVLA does not begin until 1.7 years after commencement of the project, so there is time to make these procurement plans during the early design and development phase of the project. The only electronics subsystems where production components are needed immediately after commencement of the project are the 22 and 45 GHz receivers where it is planned to complete the ongoing production and installation of these receivers. For these receivers reliable component vendors have been used for several years and a supply of components for the next year's worth of receivers are already in-house.

All purchasing for the EVLA Project will be performed by the Socorro Business Division, with additional purchasing personnel funded by the Project as needed. The Socorro Business Division is well experienced in the procurement of the kinds of materials and services (M/S) needed for the EVLA. The EVLA will cause an approximate 60% increase in the dollar volume of M/S expenditures supported by the Socorro Business Division.

2 Scientific Issues

The first questionasked for an explicit statement of the high-level scientific goals of the EVLA project, including required sensitivity, spectral coverage, bandpass, flux, phase, polarization accuracy, and frequency resolution. We interpret this as a request to justify the stated technical goals of the EVLA project on the basis of projected scientific capability.

The Very Large Array was not designed with any particular experiment or scientific goal. Rather, it was designed to provide astronomers with a powerful and flexible instrument for research into all phenomena which emit (or reflect) detectable radiation in the radio band. The VLA merged the newly-developed technique of aperture synthesis with (then) modern technologies to provide a ten- fold to one hundred-fold improvement in observational capabilities over existing instruments. The fruits of this design philosophy are evident in the astounding impact the array has had upon science -- as outlined in Chapter 1 of the EVLA proposal.

The goals of the EVLA project are based on an extension of the same philosophy which has proven so effective for the original VLA. We seek to improve by at least an order of magnitude all key observational capabilities of the VLA through implementation of modern technologies. Improving the capabilities of the existing array, rather than (say) designing and building an entirely new facility is a cost-effective approach to maximizing the science return while minimizing the capital investment because the information-gathering capability of the present array remains largely untapped. This is so because the 1970s technologies used for signal collection, transport, and analysis, being limited to narrow bandwidth, can process only a very small fraction of the information collected by the antennas. As the VLA still utilizes this >20-year-old technology, the array is severely limited in its observational capabilities compared to the potential set by the antennas and array design. Implementation of modern signal processing technologies can completely remove the narrow-bandwidth restrictions imposed on the VLA's designers some 25 years ago, and enable all the information collected by the antennas to be processed for maximum scientific return, without having to design and build a new instrument, or develop a new site and infrastructure.

The scientific impact of the expanded capabilities of the EVLA will be enormous, and has been described in detail in the Appendix to the proposal. Some especially outstanding examples of the new science to be expected are highlighted in Chapter 4 of the proposal. These examples were selected to demonstrate the broad reach of the new instrument, but should not be considered as individual science goals. Indeed, we fully expect that the most outstanding new science will be in areas not anticipated by us, just as many of the VLA's outstanding accomplishments were not anticipated by it's designers.

2. Technical Issues

2.1 Technical Goals of the EVLA Project

The first question asked how the various technical goals of the project were set. In short, they were set by establishing a goal of providing the astronomer with all of the astronomical information available at the antennas' feeds.

Individual technical goals for the project were set in the following ways:

- **Sensitivity** The general goal of 1 microJy rms in 12 hours observing between 2 and 40 GHz is set by consideration of the system temperature, bandwidth, and system efficiency which can be provided by modern technologies. For all of these, we have set ambitious, but realistic, goals which we are confidentcan be met. For nearly every band, the system temperature goal is dominated by one of ground spillover, galactic emission, or atmospheric thermal emission. The proposed bandwidths include nearly all the frequency span of each band, and the proposed antenna efficiency is the best that the VLA's existing antennas are capable of.. In short, once these improvements are in place, the full information collecting ability of the existing antennas and array will be utilized.
- **Spectral Coverage** Our goal is to make available to the astronomer the entire spectral range between 1 and 50 GHz. This can be achieved, with the sensitivity goals listed above, with eight Cassegrain receiver systems. Although our current plan defers frequency coverage below 1 GHz to the 2nd phase of the project, we will review this decision in conjunction with our scientific advisory panel.
- **Bandwidth** Modern technologies enable efficient, cost-effective transport of up to 8 GHz of IF bandwidth in each polarization. This is the bandwidth goal of the ALMA project, and its implementation into the EVLA means that nearly all of the available information in any of the eight Cassegrain frequency bands will be instantaneously available to the correlator for processing. The ALMA project has already done the necessary design for these bandwidths, and the EVLA will simply utilize their technology.
- **Phase** The phase stability design goal of the VLA was 1 degree per GHz. This ensured that the effective phase stability of the array is completely dominated by atmospheric instabilities. The same goal will be set for the EVLA electronics, and will be straightforward to meet. The effect of

atmospheric instabilities has been eliminated for stronger target objects through the algorithmic invention known as 'self calibration'. The greatly expanded sensitivity of the EVLA will permit this technique to be applied to much weaker objects -- indeed, estimates indicate that all observations in the 1.5 and 3 GHz bands will benefit from this technique, and perhaps even all observations in the 6 GHz band. For higher frequencies, we anticipate improved use of rapid switching methods (as the number of available nearby phase calibrators will vastly increase),and use of WVR radiometers, which can monitor the phase path through the atmosphere.

- **Flux** This is addressed under 'Sensitivity'
- **Polarization accuracy** The existing polarization purity of the feed systems is 2 - 5%. This goal will be maintained for the full-bandwidth feeds, and is expected to be met, except perhaps near the band edges. These polarization errors can be accurately removed, so long as they are constant in time. Experience shows that a corrected (linear) polarization accuracy of 0.1 to 0.5% can be achieved, and this should not change for the expanded systems.
  This accuracy is more than sufficient to meet the requirements of the science examples given in the proposal. We would like to do better, and studies of the temporal and spatial variability of the polarization response will continue.
- **Frequency resolution** The highest frequency resolution for cold emission or absorption lines is about 500 Hz. A much more demanding frequency specification is based on reflected radar signals from planetary bodies (bistatic radar), for which frequency resolution of about 1 Hz is desirable. The WIDAR correlator design meets these specifications, as well as providing sufficient numbers of channels to allow accurate measurement (and subsequent subtraction) of the surrounding continuum emission. This very high frequency resolution will also enable containment and removal of RFI signals within the observing bands.
- **BANDPASS Stability**

3. EVLA Subsystem Definition

The major EVLA hardware and software subsystems are shown schematically in Figure 3. A brief definition of each subsystem, and the plan for supplying the subsystem, is provided below.

~~3.1 Proposal Preparation and Submission~~

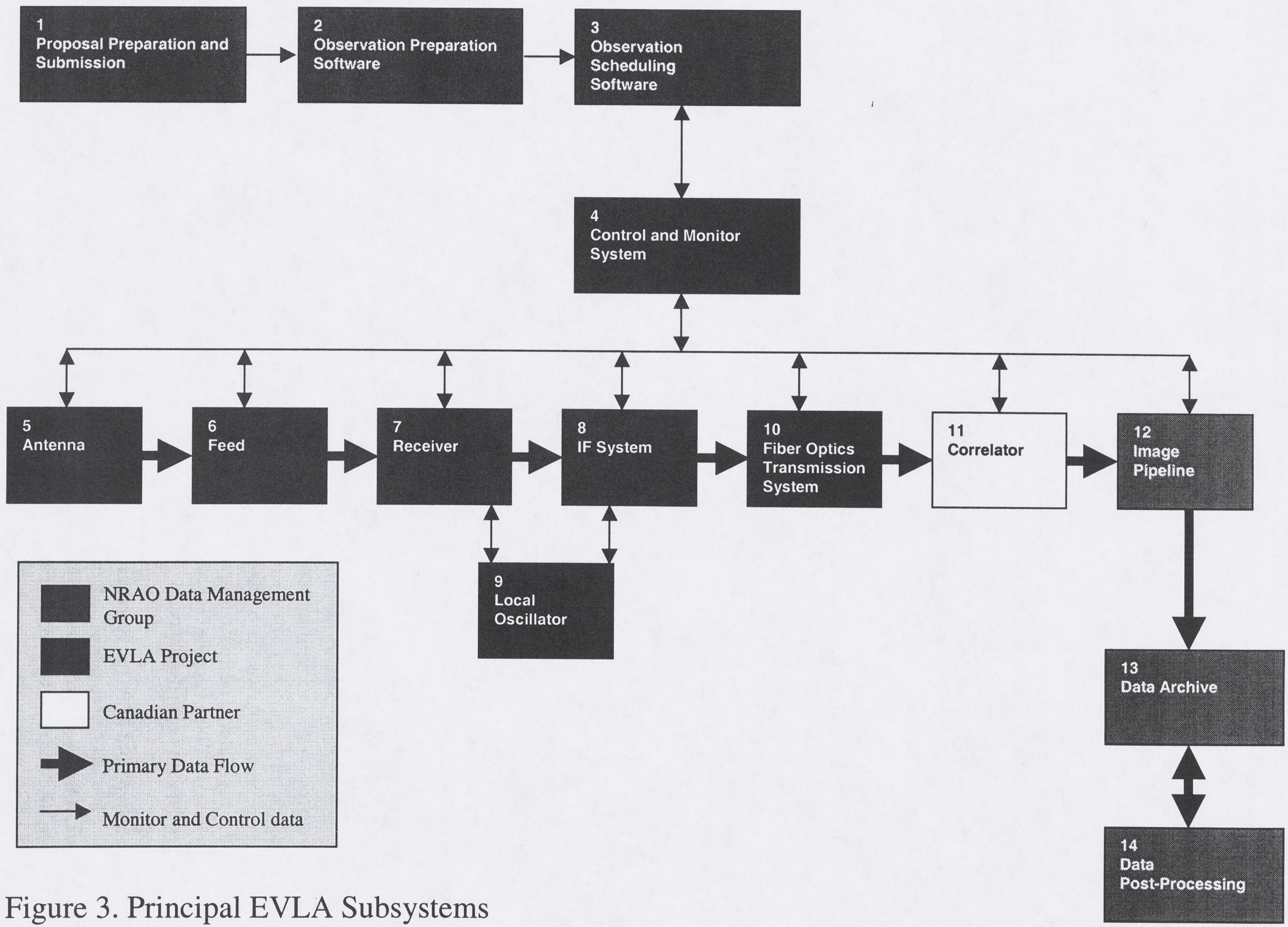


Figure 3. Principal EVLA Subsystems

3.1 Proposal Preparation and Submission

Information submitted by the observer will be maintained and carried through the entire computing system so that at the completion of an observation, the archive will include proposal cover sheets, telescope schedules, observation status information, the observed data, an automatically generated "reference image," and information entered during subsequent data reduction. The scientific proposals for the EVLA will be handled by a suite of tools that will comprise capabilities for proposal composition, including integration with the observation preparation software so that observers may experiment with various telescope parameters to assist in the refinement of the proposal; electronic proposal submission via the web and electronic mail; and proposal evaluation aids for the review committees. This work has a parallel for other NRAO instruments, so these items will be developed under internal contract by the Data Management group.

3.2 Observation Preparation

EVLA observations will be conducted using goal-oriented observing procedures, interactive graphical user interfaces (GUIs), or detailed observing plans, including the script files that are currently in use at the VLA. The Observing System will provide tools for the preparation of these observation plans. The script will include contextual information needed for the pipeline processing of observations. This work also is important for other NRAO instruments, so these items will be developed under internal contract by the Data Management group.

3.3 Observation Scheduling

Both fixed and dynamic scheduling will be used to allocate time on the EVLA. Fixed scheduling will be used for activities requiring specific observing times. Dynamic scheduling will enable the best use of the remaining array time. A Dynamic Scheduling tool will assist in the scheduling of observations on the telescope, matching observing conditions to observations in an optimal fashion. A dynamic scheduling tool has been developed for the VLBA, and will be adapted for use on the EVLA. The NRAO Data Management Group will be responsible for this development.

3.4 Control and Monitor System

The Control and Monitor (C&M) System will accept programs from the observation scheduling system and perform the observations under the control of the EVLA operator and scientific support staff. Interaction with the EVLA will be possible from any remote location with adequate, secure Internet access. The C&M system will provide continuous feedback to the observer, and will enable interactive adjustment of the observing program by the observer. Important milestones in the progress of the observations will be logged and associated with the observed data. The system will be designed and implemented by the Array Support Group (ASG) of the Socorro Computer Division; this will include the acquisition of the appropriate computer equipment.

3.4.1 Control and Monitor Software

The C&M System will provide a complete and well-integrated tool suite to test, control, monitor, maintain, and calibrate the instrument. It will be available for use by observers, by operations staff, and by scientific, computing, and engineering support personnel. All aspects of the EVLA will be accessible via this tool suite - array and subarray configuration, scan configuration, tools to monitor, operate and maintain the antenna, feeds, receivers, IF system, maser, LO system, signal transmission, the correlator, and ancillary subsystems such as the weather station and radio frequency interference monitor. Measures of data quality from the correlator, and tools to access archived systems data will be provided. Network software (middleware) will mediate the exchange of monitor and control messages among the system components. Choices here are being evaluated.

3.4.2 Control and Monitor Hardware

The C&M system will be a distributed computing architecture. It will be possible to control and monitor all hardware from a remote location via an authorized, secure network connection. In the control building, the Array Control computer will issue commands to each Antenna Control computer via an Ethernet fiber-optic network link. In each antenna, an Antenna Control computer will issue commands to its sub-systems via a local field bus. The Array Control computer and the Antenna Control computers will be commercial, off-the-shelf (COTS) equipment - Pentium and/or PowerPC CPUs in CPCI and/or VME crates. The Ethernet connection among these CPUs will run the industry standard TCP/IP protocol. The local field bus within each antenna will either be COTS or a modification of the NRAO-developed Monitor & Control Bus (MCB). The COTS candidates are Controller Area Network (CAN), and Ethernet.

3.4.3 Parallel Operation

During construction, it will be essential to operate existing VLA antennas in parallel with the enhanced EVLA antennas. Operationally, the enhanced EVLA antennas will form a separate subarray used to debug the new electronics and the EVLA C&M software; the present VLA computer control system will be used to control existing VLA antennas and the existing correlator, while the enhanced EVLA antennas and correlator will be controlled by the EVLA control system. Monitor and control information must be coordinated between the two systems. Building upon lessons learned from the VLA-VLBA (Pie Town) link, an enhanced VLA Serial Line Controller, which can control VLA antennas and interface with the EVLA C&M system, is currently in development.

3.5 Antenna

The only significant changes to the VLA antennas planned for the EVLA (Phase I) are the modification of the feed/receiver mounting structure located in the center of the primary reflector. This structure will be designed and installed by the Socorro Engineering Services Division. Fabrication of the structures will be by contract to an outside machine shop.

3.6 Feeds

The frequency ranges and principal performance requirements for the eight EVLA receiver bands are listed in Table 1 which is taken from Tables 3.1 and 5.1 of the Proposal.

Table 1. Principal performance requirements for the EVLA

Band Center Frequency (Ghz)	Frequency Range (Ghz)	System Temperature (K)	Total System Efficiency	Maximum IF Bandwidth (GHz)
1.5	1.0-2.0	26	0.50	2x1
3.0	2.0-4.0	29	0.62	2x2
6.0	4.0-8.0	31	0.60	2x4
10	8.0-12.0	34	0.56	2x4
15	12.0-18.0	39	0.54	2x6
22	18.0-26.5	54	0.51	2.8
33	26.5-40.0	45	0.39	2x8
45	40.0-50.0	66*	0.34	2x8

* At low frequency end of the band

To cover the frequency bands listed in Table 1, new corrugated horn feeds will be provided for the 1.5, 2, 6, 10, 15, and 33 GHz bands. Additionally, new feeds for the 22 and 45 GHz bands will be provided for those antennas that have not already had new receivers installed for those two bands. Twelve 22 Ghz and three 45 Ghz receivers remain to be built and installed. The feeds will be designed to provide the aperture efficiencies listed in Table 1. The feeds will be designed by the NRAO Central Development Lab (CDL) and fabricated by the Socorro Electronics Division by contract to an outside machine shop.

3.7 Receivers

The existing VLA receivers for the 1.5, 10, 22, and 45 GHz bands will be modified to provide the tuning range and IF bandwidth listed in Table 1. Completely new receivers will be provided for the 3, 6, 15, and 33 GHz bands. The noise temperatures to be achieved are listed in Table 1 for all receivers.

The receivers will be designed, assembled, and tested by the Socorro Electronics Division. The cryogenic low-noise amplifiers for all receivers will be built by the CDL. Other electronics components for the receivers will be purchased from outside suppliers and mechanical parts will be fabricated by contract to outside machine shops.

3.8 Intermediate Frequency (IF) System

The IF bandwidths to be provided for each band are specified in Table 1. To achieve these bandwidths a new IF system will be provided for every VLA antenna. The outputs for all bands will initially be converted to an 8-12 GHz IF band and then down-converted to a 2-4 GHz band which is bandpass-sampled by a 4 Gs/sec, 3 bits/sample digitizer. It is expected that ALMA designs will be used for the 2-4 GHz IF and digitizer stages. The Socorro Electronics Division will design the 8-12 GHz stage and will build the entire IF system, using outside contracts for PC board fabrication and assembly where feasible.

3.9 Local Oscillator (LO) System

A new LO system will be provided for every VLA antenna to support the new IF system. A fixed first LO selectable in the range 12-58 GHz, in steps of 1 GHz, will be used for the first frequency conversion and an 8-16 GHz synthesizer will be used for the final down-conversion. Local oscillator offset and fringe rotation will be supplied by a Direct Digital Synthesizer (DDS) providing an offset frequency to the 8-16 GHz synthesizer. LO reference signals will be supplied at the antenna on an optical fiber which has a round-trip phase measurement system to allow the line length to be stabilized. It is expected that the designs for the DDS and 8-16 GHz synthesizer will be small modifications similar to ALMA designs. All other LO design work will be done by the Socorro Electronics Division, who will build the whole LO system using outside contracts for PC board fabrication and assembly where feasible.

3.10 Fiber Optics Data Transmission

A fiber optics digital data transmission system will be installed to all VLA antennas. The data from the digitizer will be returned to the Central Electronics Building on twelve 10 Gbps links using commercial OC-192 technology. It is expected that the ALMA design for the digital transmission system will be used. The fiber optic cables will be installed by an outside contractor. The Socorro Electronics Division will build and test all electronic and optical equipment.

3.11 Correlator

The EVLA correlator will be funded and built by the Canadian Partner. The Hertzberg Institute of Astrophysics will design and construct the correlator using their Wideband Interferometric Digital Architecture (WIDAR) Correlator design. The correlator will process the data from 32 stations with a total bandwidth of 16 GHz per station in 2 GHz baseband slices. At the widest bandwidth the correlator will provide 16,384 spectral channels per baseline.

3.12 Image Pipeline

In order to produce images and spectra from observations as soon as they are taken, the correlated data will be passed though an image pipeline. The pipeline will calibrate and image the data using canned procedures. The procedures will contain heuristic methods driven by the goal-oriented descriptions of the observation supplied by the observer. The heuristic methods will make use of the status information about all EVLA components to provide a "reference image" from the data. For many observations, this will be sufficient for use by the observer, or at the very least will serve as a starting point for subsequent additional processing by the observer. The pipeline will be implemented using the extensive scripting and synthesis data reduction capabilities of the AIPS++ package. AIPS++ has been developed by an international consortium of observatories led by the NRAO. The most recent release of AIPS++ (version 1.4, released November 2000) contains a complete suite of applications for reduction of radio aperture synthesis data, including editing, calibration, image, image enhancement, and displays of image and all intermediate products. The development of pipeline processing is also being developed for other NRAO instruments, so these items will be developed under internal contract with by the Data Management group.

3.12.1 Data Post-Processing Hardware

We have made a detailed analysis of the scope and nature of data processing that will be needed by deployment of the full EVLA. This report is included in this document as Appendix 2. Just as for the VLA, there will be a spectrum of data processing needs. With reasonable predictions for the growth in the computer industry (e.g., Moore's Law continuing to the end of the project), we expect to be able to process the data from the most demanding observations with the EVLA using a moderately parallel cluster within the costs budgeted in the original Proposal. Many more typical observations will be entirely processable using a desktop computer. The numerically intensive parts of AIPS++ are able to take advantage of parallel and distributed computing environments in order to support the data processing requirements of the EVLA. A collaboration between NCSA and NRAO has led to AIPS++ parallel codes for the most demanding parts of synthesis data reduction: spectral line imaging, wide-field imaging, and mosaicing.

3.13 Data Archive

The data archive is an integral part of the EVLA data pipeline. As a result of an observation, all of the original correlations with the ancillary data that describe the observations, the conditions during the observation, and the reference image produced by the pipeline will be archived. In the majority of cases, the reference image produced by the pipeline and stored in the archive will constitute a scientific result that does not require further data reduction. Example ancillary data to be archived with visibility data are: observational meta-data (source positions, bandwidths, etc.), proposal cover sheet, observing schedule, operator log, monitor data from all hardware, reference pointing data, derived calibration information, interferometer model accountability data, reference images, and pipeline scripts used to process the data to reference images. After an observation has been stored in the archive, it will be possible to retrieve the data to apply data post-processing tools to the data in the archive to produce additional scientific results. It will be possible to treat the data in the archive as if it were being provided by the telescope in real-time. All data that affect the production of scientific data products are to be archived along with the visibilities. The analysis of EVLA computing needs estimates that typically the average data rate from the EVLA will be from 50 to 100 terabyte per year. Although this is very large by today's standards, we expect that at the end of construction, the cost of such storage will be in the range \$50K - \$100K. It is likely that the data will be stored in a heterogeneous array of computers, rather than on a single, large computer. Approaches to and tools for large (multi-terabyte), distributed databases are currently being evaluated. There will be a system for data distribution via a portable medium to researchers. The archive will be searchable from any authorized location on the Internet. The design and implementation of the archive will be leveraged on other efforts presently in place (e.g., HST, IPAC, Sloan) and in development (the National Virtual Observatory) in the wider astronomical community. If appropriate, the archive will be out-sourced to an organization that already serves large databases to the community. The archive will enable EVLA results to be used (after the usual proprietary period) in the National Virtual Observatory initiative, thus enhancing the scientific impact of the array. This work is also being developed for other NRAO instruments, so these items will be developed under internal contract by the Data Management group.

3.14 Data Post-Processing

Post-processing software will be provided in the AIPS++ package. End-to-end processing of current VLA data is supported by the most recent releases. Some development of new capabilities is needed for radio frequency mitigation, but these are well-understood in principle and can be accommodated within the AIPS++ package. These items will be developed under internal contract by the Data Management group.

3.15 Network Connectivity

Interaction with the EVLA will be possible from any remote location with adequate, secure Internet access. Remote access will be needed for proposal entry, observation preparation, observation tracking, data quality monitoring, archive query and retrieval. It will be necessary to upgrade the Local Area Network (LAN) at the VLA site and at the Array Operation Center (AOC) to support the predicted increased data flow from the EVLA. We will need to improve the access to the EVLA via higher performance Wide Area Network (WAN) services. We are partners with local universities in New Mexico in a recently funded effort to provide such services to Internet2 (Abilene). The Socorro Computing Division is responsible for the necessary improvements to network connectivity.

3.3 Justification of the WIDAR Correlator

The new correlator for the EVLA will be built by the correlator design group of the Herzberg Institute of Astrophysics in Penticton, B.C. This sub-project is contributed under the auspices of the North American Program in Radio Astronomy (NAPRA), which seeks to establish collaborative ventures for the development and construction of instrumentation for the EVLA and other joint radio astronomy programs.

The HIA group's novel design, called WIDAR*, has many important performance advantages for the EVLA over traditional designs. Below we list the key advantages, compared to a correlator with the same total bandwidth based, for example, on the existing ALMA design. These advantages are of particular importance for centimeter-wave astronomy.

3.3.1 More spectral channels at all bandwidths

The improvement factor over the ALMA design varies with total bandwidth, and is greatest at the maximum bandwidth of 8 GHz/polarization, with 16 times as many channels.

This is extremely valuable for spectral line searches and wide-redshift surveys -- a major future use of the EVLA, and to minimize the effect of RFI. More spectral channels at maximum bandwidth also enables wide-field mapping without having to sacrifice sensitivity by "stopping down" the bandwidth.

3.3.2 Sub-Hz spectral resolution

Bistatic radar experiments on planetary bodies require ~1 Hz resolution or better with full polarization, plus wideband continuum capability. The WIDAR design incorporates these capabilities. An ALMA-based correlator will require re-design.

3.3.3 Sub-banding Capability

The WIDAR design can independently target 128 frequency-selectable, variable-resolution sub-bands. This capability is not possible in an ALMA-like design, and is an enormous advantage for centimeter-wave astronomy, where RFI concerns make it likely that certain frequency ranges must be prevented from entering the correlator.

It also confers the ability to simultaneously target multiple spectral lines while maintaining enough bandwidth for good continuum sensitivity.

3.3.4. RFI-robustness

The WIDAR design has four special characteristics, making it uniquely robust against Radio Frequency Interference (RFI):

i) Very high spectral dynamic range. Simulations demonstrate up to 55 db spectral dynamic range, due to a combination of 3-bit digitization and suppression of harmonics and intermodulation products that tend to cause spectral "spreading" of RFI.

ii) The sub-band's "tuning" capability permits RFI avoidance. If RFI does occur with a sub-band, its effects are limited to that single sub-band.

iii) Time-variable RFI can render the entire band of an ALMA-like correlator to become uncalibratable. The WIDAR correlator confines these effects to the the sub-band in which it occurs, and even that band's calibration can usually be recovered.

iv) The very high number of spectral channels means that in most cases, the actual frequency resolution is very high. Even in RFI-crowded environments, most RFI is narrow-band in character. If RFI does occur, its effects are limited to the few channels surrounding the frequency of the RFI, leaving the rest for astronomy.

3.3.5 Digital sub-sample delay capability

Most correlator systems require an analog method of correcting for sub-sample delay errors, and are forced to compensate the entire band at once. The WIDAR technique permits delay errors to be compensated for each sub-band individually. This results in predictable and greatly reduced coherence losses at the band edges.

3.3.6 The use of FIR filters to define the sub-band shapes

These digital filters give precisely defined, extremely stable bandpasses. This will result in minimal 'closure' errors. Closure errors cannot be corrected for by standard 'self-calibration' techniques.

3.3.7 The design is 'VLBI-ready'

The correlator can accept signals from distant stations either in real-time or from tape. Thus, the correlator will enable real-time or tape-based operations for any of its defined subarrays. Some sub-arrays can operate from tape while others are performing real-time correlation.

3.4 (NEW MATERIAL TO BE INSERTED)

3.5 Radio Frequency Interference

Radio frequency interference causes problems for all radio astronomy telescopes, especially at frequencies below ~3GHz. This is expected to worsen over time as the radio spectrum usage increases. The protected bands constitute a unique "wilderness" area for radio astronomy that needs vigilance to protect its status. Outside of the protected bands, radio astronomy is possible at various frequencies depending on the exact level and nature of use by other services. Since radio astronomy is entirely passive, this use is allowed and leads to signficant science, such as the detection of red-shifted lines. Indeed - full-band usage is necessary to achieve the sensitivity goals of the project.

Both inside and outside the protected bands, RFI may be present and will need mitigation. Radio astronomers have a number of countermeasures that can and must be deployed. Following the signal path, these are:

- Filters in the antenna front-ends can protect against very strong specific fixed interference. In addition the receivers should have sufficient overhead that saturation of the amplified signal is unlikely.
- The incoming signal must be digitized with sufficient accuracy (3 - 4) bits over a maximum bandwidth to minimize significant cross-modulation of strong interfering signals into the spectrum of interest.
- The correlator must offer protection against cross-modulation. As noted above, the WIDAR correlator design is particularly effective in dealing with RFI.
- Post-correlation adaptive cancellation techniques pioneered at the ATNF use the consistency of interference between different antennas to identify and remove strong interfering signals. This requires high sampling in both time and frequency so the data must be averaged down after this type of processing, prior to calibration and imaging. We would expect that a specially dedicated parallel machine placed between the correlator and the image pipeline would perform this task.
- Finally, any residual RFI can be detected and removed during the calibration and imaging process. Most of these techniques exploit consistency in Fourier space, time or frequency to identify RFI.

We expect to employ all of these countermeasures in one form or another in the EVLA. The main area needing development is that of post-correlation adaptive cancellation, where research by a number of groups around the world is proceeding. Since this is a research area and the need for such cancellation is evolving, we have not specifically included funding within the EVLA budget. Funding will be sought separately. We will monitor progress in the area, and develop a proposal at a later time. What is important at this time is not to design out capabilities which may prove useful later.

2.4. Contingency Plans for EVLA Correlator

One of the questions asked what are our ontingency plans in case of late delivery or cancellation of the Canadian correlator.

The WIDAR design, proposed by the correlator group at the HIA in Penticton, B.C. has very attractive and desirable characteristics which make is a superior correlator over other correlator designs for the EVLA. However, Canadian funding for this correlator is not assured, and we must plan our reaction to a potential failure on their part to secure the necessary funding.

It is our conviction that the advantages of this correlator design for centimeter-wave astronomy are so significant that we would seek to construct a correlator ourselves, using the WIDAR design. This could be done by one of various routes:

a) Contracting the correlator group at the HIA to build the correlator, using our resources, or
b) Hiring the principal members of that group to build the correlator at the NRAO, or
c) Developing our own correlator group, to design and build the correlator, using the WIDAR design. This option is much the least desirable.

Each of these scenarios will require us to find additional funding to make up for the loss of Canadian funding. This might be done by looking for further external partners, or, probably more likely, by seeking additional resources from NSF funding -- either has requesting supplemental monies from the NSF, or by savings accrued by 'descoping' other aspects of the technical goals for the EVLA Project. Such descope options could include:

a) Elimination of one or more frequency bands.
b) Reduction in the total available bandwidth.
c) Reduction in computing and operational capabilities.
d) Reduction of capability of the correlator.

Note that all of these will result in a significant reduction in the scientific productivity of the EVLA.

Another option would be to adopt the ALMA correlator design. This is not a 'free' option -- the ALMA design does not provide the ~1 Hz resolution necessary for planetary radar experiments, is not 'VLBI-enabled', has considerably lower spectra dynamic range, provides only 1/16 the number of channels at full bandwidth, and must further be modified to enable pulsar observing. Design modification will be necessary to fit that correlator design to the needs of centimeter-wave observing. We do not wish to adopt this fall-back solution, and would only do so if it were necessary to abandon any hope of implementing a WIDAR-design correlator.