DRAFT - 2/12/82

VI. COST ESTIMATES

The VLB Array is a complex sophisticated system which is based on well understood techniques and instrumentation whose cost can be reliably estimated. No new sophisticated structural engineering is involved; designs exist for most of the electronic systems, and in many cases prototypes are already in operation on existing radio telescopes. Nevertheless, further design and engineering will be required to ensure that all sub-systems take advantage of the latest advances in the art, particularly in the rapidly evolving digital field. Indeed, experience has shown that the instrumentation will continually be modified and improved, and allowance for these improvements forms a crucial part of the operating budget.

In this chapter we describe the total construction and operating costs. We also include in this chapter a preliminary construction plan. All costs are given in thousands of dollars (1982).

A. Array Elements

Estimates for the construction and acquisition of new equipment is, in part, based on the cost of similar instrumentation in use or being fabricated for the VLA or other NRAO telescopes with allowances for escalation to 1982 as well as required design changes.

1. The Antenna Elements. Twenty-eight antennas have been built and are now in operation at the VLA. The price for a VLA type antenna modified to meet the specifications discussed in Section III-C has been determined from the known VLA costs with the following corrections:

   a) The increased cost of steel and labor due to price escalation since the original contract.

b) The increased erection costs due to the use of Union labor and lack of the NRAO supplied erection facility.

c) Shipping costs of structure to the site.

d) Manufacturer's loss on VLA antennas and profit allowance.

e) Shielding and insulating of pedestal structure.

f) Strengthening of "feed" legs.

g) Strengthening of yoke structure.

h) Higher accuracy surface panels.

In addition, there is a one time only engineering cost of $585 K made necessary by the various modifications which are required, and $115 K for tooling costs.

In this way we estimate a total cost of $17,490 K for ten antennas, delivered over a two year period.

We have not yet completed the cost analysis of the new wheel-and-track design. The cost of this antenna is reduced due to the simplicity of the structure, that is, fewer joints and fewer members are used. But this may be partially offset by the need to adopt a new design concept. There is also an increased engineering and design cost, but this is small if it is amortized over 10 antennas.

For our budget calculations we have used the cost of modified VLA type antennas. We anticipate, however, that the Array will be built using the wheel-and-track antenna concept, and we have therefore set aside the $950 K necessary for the full engineering design of this new antenna. However, the total cost of design plus fabrication of the 10 wheel-and-track antennas should not exceed the $17,490 K estimated cost of the modified VLA antennas, and is expected to give improved performance at the shorter wavelength. In addition to the basic antenna structure, the non-manufacturer supplied items in Table VI-1 are added.

TABLE VI-1

ADDITIONAL ANTENNA COMPONENTS

1)	Feed mounting ring (vertex room cover) and feed support towers	12 K
2)	Subreflector and support structure	22
3)	Focus and subreflector rotation mount	25
4)	Electrical installation	4
	TOTAL Auxiliary Antenna Equipment	63 K

To this must be added a non-recurring engineering and tooling cost of 90 K.

2. Feed System. The cost of the 10 band feed system is given in Table VI-2.

TABLE VI-2

FEED SYSTEM

Prime Focus Feeds		
327 MHz	2 K	
610	2	
TOTAL		4 K
Secondary Focus Feeds		
1.5 GHz	13 K	
2.3	11.7	
5.5	3.6	
8.4	1.8	
10.7	1.8	
15	1.5	
22	1.5	
44	1.5	
TOTAL		36.4
Polarizers		8
S/X Band Dichroic		10
Windows, Waveguides, etc.		4
Measurement and Test		20
TOTAL Feed System (per ant.)		82.4 K
Non-recurring Engineering and Development		
Materials		150 K
Labor		110 K

3. Front End System. The cost of parts and labor for the multi-frequency front end system is summarized in Table VI-3.

Because most of the individual receiver elements (e.g. cooled FET amplifiers, 1.3 and 0.7 cm masers) have already been developed or are part of ongoing programs at the NRAO, we anticipate that only a further $150 K of non-recurring engineering and prototyping will be required to develop the complete 10 band low noise receiver system.

4. Hydrogen Maser. We have obtained cost estimates for hydrogen masers from three potential suppliers. Supplier No. 1 offered no quantity discount and did not consider selling the physics package alone. Supplier No. 2 estimated a 25% cost saving if 10 units are procured at the same time, and a further reduction of $75 K per unit if the receiver/synthesizer system is omitted. The third and lowest estimate is based on a formal quotation for purchase of one unit in 1982 either with or without the receiver system, but this is from a supplier that has not yet produced a commercial grade product.

We have also considered developing the maser oscillators in house, but have rejected this as being impractical. However, since we are able to build the receiver/synthesizer system for about 1/2 of the cost of a commercial supplier, we intend to purchase the "physics package" alone from an outside supplier. We estimate the cost of the hydrogen maser oscillator in Table VI-4 below.

TABLE VI-4

Hydrogen Maser Physics Package	210 K
Receiver Synthesizer (Materials)	18
Receiver Synthesizer (Labor)	22
TOTAL Hydrogen Maser (per ant.)	250 K
Receiver Development	30 K

TABLE VI-3
FRONT END COSTS

Cryogenic Costs		Materials $ K	Labor (Man Months)	
20° K Cryogenics				
Refrigerators	6x6 K	36 K		
Compressors	3x8 K	24		
4° K Cryogenics				
Refrigerator and Compressor		50		
Helium Lines				
4 K and 20 K Systems		20		
Total Cryogenics				130 K
300° K Front End Costs				
327 and 610 GASFETS Dual Pol.	4x1 K	4 K	2	
Weatherized Package	2x0.5 K	1		
Buffer Amplifiers	4x0.25 K	1	2	
Assembly		16		
Total 300 K Front Ends				22
20° K Front End Costs				
Dewar, Input Lines, etc.		20 K	6	
GASFET Amplifiers at 1.5, 2.3, 5.5 8.4, 10.7 and 15 GHz 6 frequencies x 2 Polariz		12	6	
Mixer/IF Amplifiers (12)		12		
Local Oscillator System		20	6	
Assembly		56		
Total 20 K Front Ends				120
4° K Front End Costs				
Dewar, Input Lines, etc.		20 K	6	
Dual Channel Masers 22, 43 GHz		20	12	
Solid State and Plystron Pumps		20		
Local Oscillator System		10	6	
Mixer/IF 4x2.5		10		
Assembly		64		
Total 4 K Front Ends				144
Miscellaneous				
System Noise Calibration		15 K		
Phase Calibration		15		
Power Supplies, etc.		10		
Total Miscellaneous				40
TOTAL FRONT END SYSTEM PER ANTENNA				456 K

5. The Record System. The cost of the data acquisition system is based on using modified Video Cassette Recorders and automatic Cassette Changer. One spare rack each complete with changer, recorders and electronics is included at each station. Although only one record rack per station is required for normal operation, the second recorder allows for uninterrupted operation in case of failure of the electromechanical cassette changer, or in special cases to record with twice the normal bandwidth. This option, however, requires two passes through the Processor.

The data acquisition system consists of the IF system, the Data Digitization Electronics, and the Record Racks. The cost is summarized in Table VI-5 below.

TABLE VI-5

COST OF DATA ACQUISITION SYSTEM

IF Switching Matrix	5 K	
IF Processor	36	
IF to Video Converters	12	
TOTAL IF SYSTEM		53 K
Sampler	2 K	
RS232 Distributor	1	
Delay Calibrator	3	
Rack, Power Supplies, Connectors, etc.	10	
5 MHz Distributor	2	
Assembly (8 man months)	21	
SUBTOTAL Data Digitation Electronics		39
18 Video cassette recorders	15 K	
2 recorder racks with electronics	36	
Assembly and integration (0.25 man yrs.)	7	
TOTAL RECORDER RACKS		58
TOTAL DATA ACQUISITION SYSTEM (Per. Ant.)		150 K

6. Control and Monitor System. Each antenna element has its own minicomputer system which receives control information from the Array Control Computer and transmits data to monitor the front end and record system performance as well as meteorological data. The cost of the Array Control Computer is given in Section VI B 2. The per antenna cost is shown in Table VI-6 below.

TABLE VI-6

COST OF TELESCOPE CONTROL AND MONITOR SYSTEM

Telescope Control Computer (Includes 128k byte memory, two 10M byte disks, tele-typewriter, CRT, and manufacturer's operating system and communications software)	30 K
Interface Equipment to Antenna and Receiver (Three data-sets and serial interface to computer)	5
Fringe Verification Buffer (256k byte memory)	3
Communication Equipment - Modems	5
Dedicated Test Equipment	5
Spare Computer Parts	6
Installation Cabling ($1,000) and 1/2 man-year check-out labor	16
TOTAL PER ANTENNA	70 K

7. Site Development. The following items are included at each of the Array Stations.

a) Site acquisition and grading 5 K

b) Control building, including environmentally controlled area for instrumentation and computers, tape storage, shipping area, office space, maintenance area, and toilet.
1400 sq. ft. at $70 per sq. ft. 98

c)	Telescope foundations. Cost varies from site to site depending on terrain, etc.	50 K
d)	Emergency generator. 30 KVA to stow antenna and keep cryogenics running.	20
e)	Roads. Road requirements will vary from site to site but is taken to average 400 ft. A 12' wide road for light traffic can be constructed for $30 per foot including typical excavation and grading costs.	12
f)	Electrical power installation. 400-ft from commercial power. Underground installation at $15 per ft.	6
g)	Water supply and disposal system	10
h)	Furniture	6
i)	Maintenance equipment including small 4-wheel drive vehicle with snow plow, tools, service elevator.	35
j)	Fence (approx. 1200 sq. ft.) @ $12 per sq. ft.	12
k)	Soil Tests	6
ℓ)	Design Fee (Engineer-Architect)	25
	TOTAL Site Development (per site)	285 K

8. <u>Other Site Development</u>. The following additional items are required at each antenna element.

a)	Test equipment and miscellaneous tools	35 K
b)	Water vapor radiometer and other meteorological sensors.	35
c)	Timing equipment. Rubidium clock and timing receivers.	40
d)	Test and Installation of all station feed and electronic systems.	10
	TOTAL Other Equipment (per antenna)	120 K

B. Operations Center

1. The Playback Processor consists of the control computer, the tape playback system, and the correlator. The cost estimate in Table VI-7 is based on the VLA type recirculating correlator.

TABLE VI-7
PLAYBACK PROCESSOR (K$)

Computer System		
CPU with 2 Mbyte Memory, 100 Mbyte Disk, 800/1600 BPI Type Drive, Operations Software	$ 182 K	
2 Tape Drives 6250 BPI	67	
Array Processor, 64 K Word Memory	73	
4 Text, 1 Graphics Terminals	10	
Cabinets, Power, Furniture	10	
Software Development (3 man years)	96	
Installation (0.1 man years)	4	
Subtotal Computer		442 K
Tape Playback Unit		
16 Playback Racks	288 K	
140 Video Cassette Recorders	112	
Assembly (2 man years)	64	
Subtotal Tape Playback Unit		464
Correlator System		
Correlator Hardware	530 K	
Support Hardware	200	
Design (3 man years)	96	
Assembly (2-1/4 man years)	72	
Subtotal Correlator System		890
System Integration (2 man years)		62
TOTAL PLAYBACK PROCESSOR		1,850 K
Development (∿ 2 man-years)		60 K

2. Computing Equipment.

Processor Controller. The cost of the on-line computer which controls the Processor and handles some of the preliminary fringe fitting is included in the cost of the Processor.

Array Control Computer. Control of the Array and communications with the station computers will be through the Central Array Control Computer. An extra Telescope Control Computer is included at the Operating Center for programming support. Cost of the Control System is:

Array Control Computer (Includes 512k byte memory, two 1600/6250 bpi tape drives, two 122M byte disks, teletypewriter, printer, card reader, 2 graphics and 8 text CRT;s, and manufacturer's software for operating system, communications, and FORTRAN)	204 K
Communication Equipment - Modems	15
Telescope Control Computer (For software development)	35
Software (16 man-years)	512
	766 K
TOTAL Control and Monitor System - Central Control	766 K

Post Processing. Post processing requirements are outlined in Section IV-B in terms of the DEC VAX-11/780 system. Post processing software will depend largely on procedures already developed for the VLA and existing specialized VLBI software. An additional 10 man-years of programming effort is assumed. Cost estimates are given below:

4	VAX-11/780 with 2 Mbyte memory, accelerated I/O	850 K
4	Additional 2 Mbyte memory	72
	Disks and Controllers (10 G Bytes instantaneous, 10 G Bytes removable)	936
9	Array Processors	310
2	I^2s Image Displays	110
2	Printers	30
12	CRT terminals (9 text, 3 graphics)	30
6	High Density Tape Drives	170
	Optical Disk	40
	Video Disk	20
	DECNET System (incl. software)	32
	Misc.	50
	Total Post-Processing Hardware	2650 K
	Post-Processing Software Development (10 man-years)	320 K
	TOTAL Post Processing Cost	2970 K

3. Control Building. The control building houses the Playback Processor, the Array Control System, the computer for data reduction, electronic laboratories for development and maintenance, storage area for magnetic tapes and spare parts, office space for visitors and staff, and shipping area. 10,000 sq. ft. are required at $80 per sq. ft. which includes design fee and utility service connections at an existing operating site. Site development is $50 K.

CONTROL BUILDING	850 K

4. Magnetic Tapes. At the normal continuum bandwidth of 50 MHz, 42 tapes per day are used at each station. For most spectroscopic applications,

the number of tapes used will be very much less, while for some continuum observations, two recorders will be used to increase the bandwidth. We have allowed for a 60 day supply of tapes at an average of 42 tapes per day to arrive at a cost estimate of tapes and shipping bins.

MAGNETIC TAPES AND BINS	450 K

5. Other Operating Equipment. Funds are allocated for general and digital test equipment and for a precision Cs flying clock.

OTHER OPERATING EQUIPMENT	200 K

6. Spare Parts. The major portion of spare parts stock will be located at the Service Centers with only small components whose failure rate is fairly high being maintained at each field site. Those parts whose "mean time between failure" is greater than one year or whose failure will not bring down an entire antenna system (e.g. a single receiver module) will be stocked only at the Service Center. We estimate the following costs for spare parts in order to support and maintain operation with an average downtime less than 5 percent at each telescope.

The spare parts inventory includes the approximate equivalent of one front end, IF, digitization, and hydrogen maser system as well as the recorder and computer spares stocked at the telescopes and listed earlier.

TABLE VI-8

SPARE PARTS INVENTORY

Antenna structure and servo	330 K
Cryogenics	45
Receiver	500
Hydrogen Maser	150
Playback System	125
Computer	50
TOTAL SPARE PARTS	1200 K

VLB ARRAY

COST SUMMARY (K$)

Per Station Systems		
Antenna	1654	
Aux. Antenna Equipment	63	
Feeds	82	
Front Ends	456	
Record System	150	
Control and Monitor	70	
Frequency Standard	250	
Site Development	255	
Other Equipment	120	
Total per station	3100	
SUBTOTAL 10 STATIONS		31000
Central Laboratory		
Control System	736	
Playback System	464	
Processor	1394	
Post Processing (incl. software)	2970	
Building and Site	850	
Operating and test equipment	200	
Spares	1200	
Tapes	450	
SUBTOTAL CENTRAL LABORATORY		8264
Development		
Antenna	950	
Aux. Antenna Equipment	90	
Feeds	260	
Control	30	
Front End	150	
Record System	130	
Site Evaluation	300	
Frequency Standard	30	
Processor	60	
Post Processing	60	
SUBTOTAL DEVELOPMENT		2060
PROJECT MANAGEMENT		2000
CONTINGENCY		6000
TOTAL		49324

C. Construction Plan

Construction of the Array is estimated to require 56 months from the date of initial funding. This schedule assumes that adequate conceptual design of the antenna and electronics systems and some prototyping has been completed prior to initial funding, the Array configuration is determined, and preliminary site inspection completed. Partial operation can begin 30 months after the start of construction. The pacing item is the antenna construction; 21 months are needed between the time funding is available and the start of construction of the first antenna.

A preliminary construction schedule is shown in Figure VI-1.

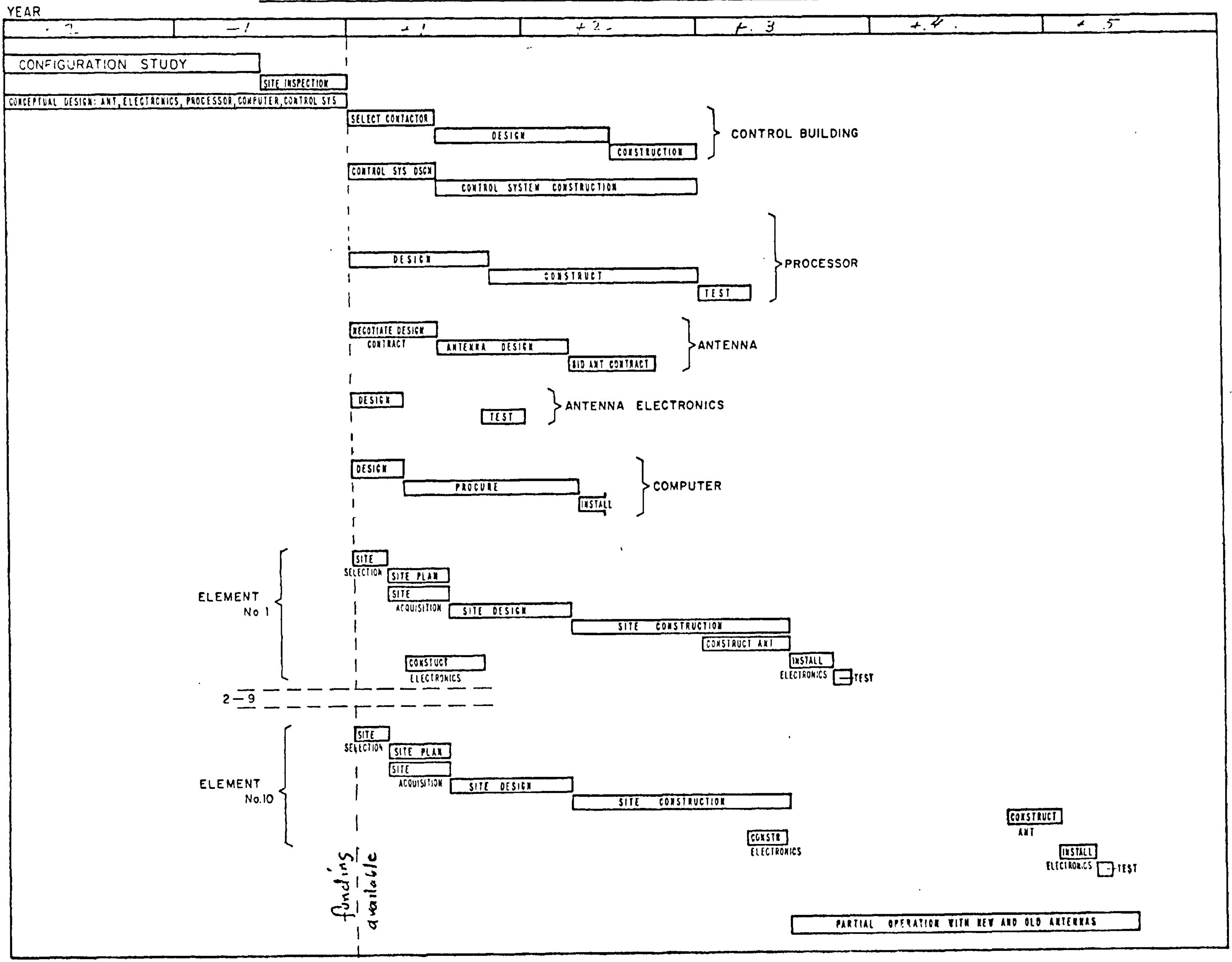
D. Operating Cost

Our estimate of the annual operating cost is based primarily on the operating costs for similar items at the VLA with particular attention to shipment of magnetic tapes and equipment, and travel between the Service Centers and Array sites. The Operating Cost is summarized as follows.

Personnel Compensation (including benefits). $1782 K

Shipping. Inexpensive shipping of magnetic tapes is available by UPS and UPS Blue Label (air). Convenient door-to-door pick-up and delivery is guaranteed in two to five days between any points in the USA including Alaska and Hawaii. The cost for a 50-lb surface shipment is between \$5 and \$20 depending on distance. Air shipment to Hawaii and Alaska costs \$60 for each 50-lb. parcel. Assuming 50-lbs. per day in each direction between each of the 10 Array Stations and the AOC at an average of \$23 per 50 lbs for 300 days per year is about \$140 K. International shipments add another \$30 K. Additional shipping costs between the Service

CONSTRUCTION PLAN VLB ARRAY



Centers and the sites, shipments from suppliers, and shipments of data to visiting observers is estimated to add another $30 K.

Total Shipping Costs $ 200 K

Travel. It is anticipated that major repair tasks will require dispatch from a Service Center of 1 or 2 technicians or mechanics and that each site will require such service approximately 8 times per year. Assuming four days of travel per repair job at $50 per day and $800 per trip gives $120 K. Additional travel to support guest investigators, professional meetings, visits to suppliers, etc. will cost $60 K.

Travel $ 180 K

Communications. The 9600 baud enhanced leased lines from the AOC to each site, including Alaska and Hawaii, required for the communications link for control and monitoring, as well as real time fringe verification, is estimated at $156 K per year. This may be reduced, particularly on the Hawaii and Alaska circuits if satellite linked facilities become available at lower cost. An additional $34 K is estimated for conventional telephone service.

Communications $ 190 K

Utilities. Each site uses about 60 KVA and the AOC about 150 KVA, corresponding to a total average power consumption of about 600 KW. The average cost of electrical power in the United States is $0.07 per KWH, giving a power cost of $400 K per year.

Utilities $ 400 K

Other Materials and Services. Material and supplies required to service the antnna elements including both consumable items such as oil, greases, paint and tools, and replacements such as mechanical and electrical equipment are estimated to cost $70 K per year, electronic parts $120 K, computer service $240 K, and miscellaneous business supplies and publications costs $150 K.

Materials and Services $ 580 K

New Equipment. $500 K per year are needed to continuously upgrade computer and electronic systems to keep the Array performing at the state-of-the-art and to expand the power of the Array. This ability to react quickly to new scientific discoveries or to technical advances is important, and is a crucial part of the operation.

New Equipment $ 500 K

TABLE VI-8

SUMMARY OF ANNUAL OPERATING COSTS ($K)

Staff	$2,100
Shipping	200
Travel	180
Communications	190
Utilities	400
Materials and Supplies	580
New Equipment	500
Management Fee	100
TOTAL Operating Cost	$4,250