Interoffice

National Radio Astronomy Observatory

Green Bank, West Virginia

April 4, 1980

ADDITIONAL BASELINE TO INTERFEROMETER
MEMO No. 124 See Up Date

To: H. Hvatum

From: F. Crews

Subject: Additional Interferometer Baseline Study

Enclosed for your review is the final draft report of the study group appointed by your memo of 8 January 1980. With the exception of Bill Meredith and yourself, each of the group has reviewed and recommends the report be approved for transmittal thru appropriate channels to the USNO.

We have made an effort to identify all tasks and costs involved, and have subtracted from the report the time and dollars of those people who are currently identified as full-time charges to the USNO and who we anticipate will work on this project. We have also subtracted the telescope encoder costs since they are being funded separately.

Additional detail to back-up our study and its recommendations are available at Green Bank.

The results of this study when finalized should be addressed to the following person:

Captain Raymond A. Vohden
Superintendent
U. S. Naval Observatory
34th and Massachusetts Ave. N.W.
Washington D. C. 20390

JFC/s

Enc.

NRAO PROPOSAL FOR ADDITIONAL BASELINE TO THE INTERFEROMETER

General:

A study of the tasks and costs involved in upgrading the Green Bank Interferometer for radio astrometry by adding an orthogonal baseline has been completed. The major decisions resulting from this study are:

(1) It is proposed that a new 40 to 50-foot telescope be purchased which is similar in design to our existing 45-ft. diameter remote telescope.

(2) A site has been located which meets the requirements for baseline length and orientation.

(3) A microwave link will be used to transmit the radiometer outputs and telescope position from the remote site to the interferometer.

(4) The existing interferometer control computer will be retained.

Site:

The site is located near Monterville, West Virginia in Randolph County. The coordinates are 38° 33' 28" latitude, 80° 09' 30" longitude with an elevation 3880 feet above sea level. The baseline length from 85-1 to this site is 31.8 km at an azimuth of 295.3°. Preliminary discussion with the owner indicates he is willing to lease the site to NRAO. A concrete foundation for the telescope will be installed. The costs of the necessary soil tests and foundation material are estimated at $14,000. Perimeter fencing will be needed.

The site should also include a telescope service elevator and pad. A standby generator capable of stowing the telescope and fuel storage for generator will be needed at a cost of $30,000.

Electronic equipment housing which is temperature controlled and a shelter for service personnel will be required. The total cost for preparing the site is estimated to be $132,600. This includes $40,800 for 2340 man-hours labor by NRAO personnel, $64,800 for material, and $27,000 for work done by outside contractors.

A preliminary plan for the site is shown in Appendix A.

Telescope:

Purchase of a new 40 to 50-foot diameter antenna is the best solution to the problem of providing a reliable, remotely-operated telescope. The reasons for this decision are as follows:

(1) The existing 85-foot antennas require much more maintenance than the 45-foot antenna.

(2) The task of snow removal from the surface area of an 85-foot antenna is substantially greater than with the 45-foot. The annual snowfall at the Monterville site is expected to be two or three times the snowfall at Green Bank.

The cost of dismantling an 85-foot antenna, upgrading the drive system to make it reliable enough to operate in an unattended location, designing a servo system to provide for remote operation, and moving and reassembling the antenna is estimated at $885,000. The estimated cost of a new 40 to 50-foot antenna, with telescope drive and readout, focus mount, drive and readout, instrumentation cables, etc., assembled at the remote site is estimated to be

$934,000. The cost of the larger foundation required at the site for an 85-foot antenna is $45,000 compared with $9,000 for the smaller antenna.

(3) The estimated cost for a new 40-50 foot antenna and foundation is $943,000, compared with $930,000 for relocating an 85-foot antenna.

(4) Forty-one more man-weeks of NRAO personnel time is required to complete this project if an 85-foot antenna is moved compared with purchasing a new antenna.

(5) If the 85-foot telescope is relocated to the Monterville site, it will be necessary to hire a full-time caretaker and at least one and possibly two full-time maintenance people because of the more hostile weather environment, the resulting vulnerability of the 85-foot, and the existing reliability problems of the 85-foot.

The specifications for the new antenna have been prepared (Appendix B). A summary of the specifications have been furnished to 32 prospective vendors for an expression of interest for engineering and fabrication. Four (4) have responded affirmatively.

Link:

A two-way microwave link will be required to provide a phase-stable local oscillator signal at the remote site, to transmit two 30 MHz wideband radiometer outputs to the interferometer control building, and to transmit antenna control and antenna position information to and from the remote site. The microwave links will operate in the 16 to 18 GHz frequency band. A study has been made of possible microwave link paths between the remote site and the interferometer control building. Adequate signal levels can be obtained by using passive reflectors to obtain the required path clearance as shown in Appendix C. The estimated costs for the new microwave links and upgrading the existing Green Bank to Huntersville links is $259,000. This includes 137 man-weeks labor by NRAO personnel, $143,000 for material, and $4000 for work performed by outside contractors.

Computer:

It has been concluded that the existing control and data acquisition computer should be retained. This computer can be used to operate the expanded four-element interferometer with a minimum of hardware and programming changes. Two new hardware ports would be added to interface with the new antenna link and the proposed data analysis computer. The cost of implementing these ports is included in the link cost figures. It is estimated that the programming changes would require 13 man-weeks of programming at a cost of $11,300. At the present time NRAO does not have available a qualified person to do this programming. The other problem is that there is no programming support for the existing interferometer software. This increases the time required to restore the system to an operating condition when a malfunction stops the computer. Lack of programming support prohibits even minor changes or corrections to the computer program. One possible solution is for the Naval Observatory to provide a programmer who will make the necessary program changes, provide documentation of the complete program, and train one or more of our NRAO personnel in program diagnostics.

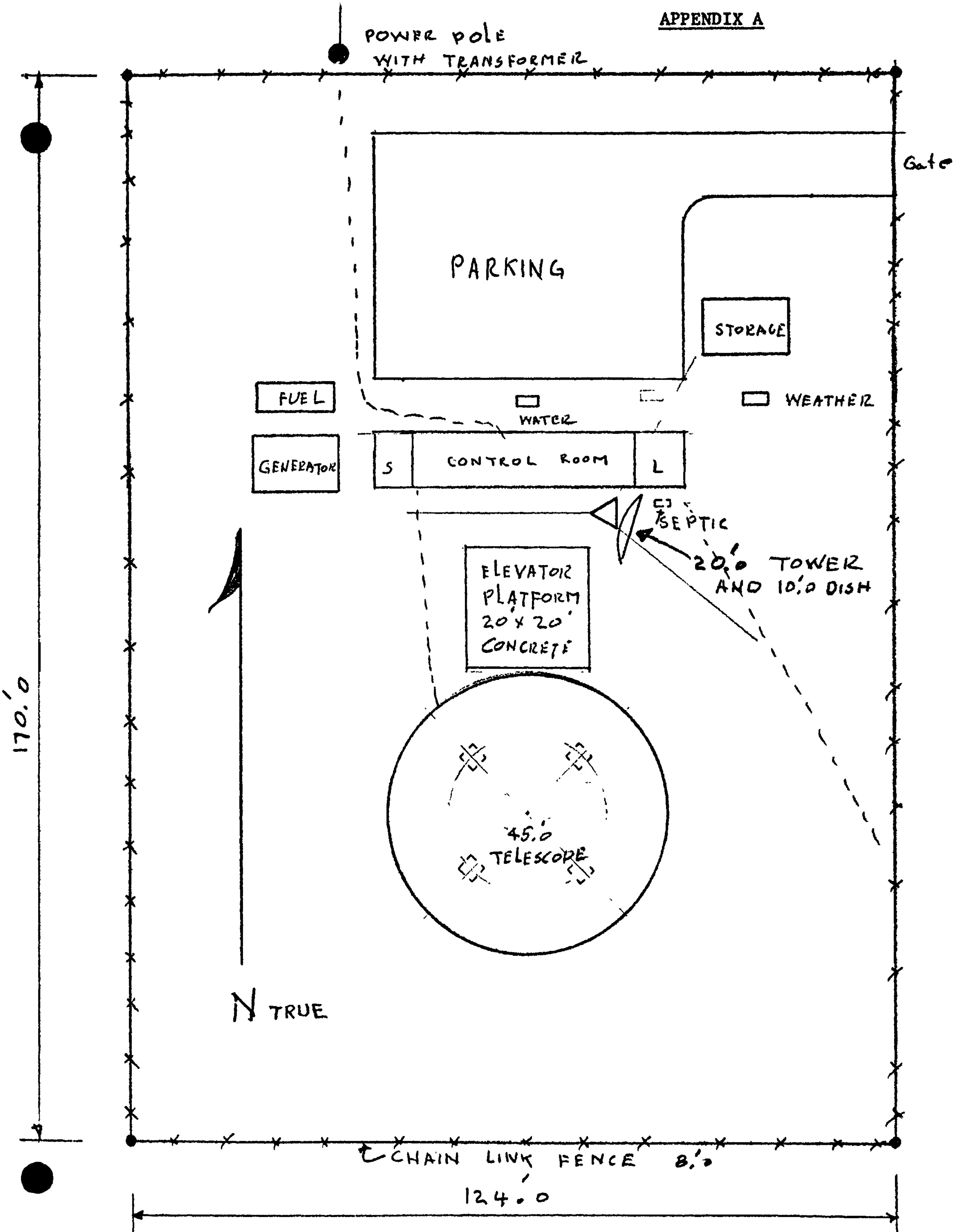
Total Costs:

The cost estimates for this project are: 1) $934,000 for the telescope, 2) $132,600 for the site, 3) $259,000 for the link, and 4) $11,300 for computer programming for a total of $1,336,900. From this total the cost of the man-hours of the NRAO personnel who are paid by the Naval Observatory for operating the current interferometer program can be subtracted, leaving a total of $1,228,000. A 15% contingency fund must be added for a grand total of $1,412,200. These cost estimates are in March 1980 dollars and do not include any provision for labor or materials escalation. The actual costs incurred will be charged to the project which may be above or below this figure, but we have used the best estimates available at this time. There will also be an increase in the annual interferometer operating costs for transportation, land leases, electric power, maintenance, etc., when the project is started.

Personnel Requirements and Time Schedules:

We estimate that this project can be completed over a time period of three years without hiring additional personnel if the present level of staffing at Green Bank is maintained. To complete the project in three years, we will need a minimum of $900,000 of the funds available at the start of the project, and the remainder a year later.

Enclosures: Appendices A, B and C



SITE PLAN SCALE 1" = 20.0'

- PROPOSED -

3/10/80 S.C.S.

APPENDIX B

SPECIFICATIONS
for
AN ANTENNA FOR A RADIO TELESCOPE

Introduction

General Statement of Work

The work described herein shall consist of the furnishing of all labor, materials, services, drawings, data and other items required for the detailed design, fabrication, shipping, erection at the subcontractor's plant and on site, alignment and testing of an antenna.

Objectives of the Program

The objectives of the effort under this subcontract are the following:

The design and manufacturing of an antenna that meets the operating parameters and requirements set forth in this specification.

It is the intent of the RFP to utilize an existing design of the subcontractor to maximum extent, preferably a design that is in production and operation, that might be modified to meet those specifications.

A design that takes into consideration ease of maintenance and the reliability of components to minimize maintenance.

Fabrication of antennas using the techniques and tooling developed and specified in the design effort.

Erection and alignment of the antennas according to the specifications and procedure.

Performance of tests to establish that antennas meet specified performance requirements.

Design and Performance Parameters

The antenna shall be an elevation over azimuth configuration with a solid surface paraboloid of revolution as the main reflector. The observing systems to be used shall be both Cassegrain and prime focus. Use of a prime focus observing system shall be considered the normal mode of operation.

Mechanical Parameters

Diameter - Min. 12.25 meters - Max. 15.25 meters

Focal Length - As determined by f/D

f/D - 0.36 minimum to 43 maximum

Sky Coverage - Elev. -10^{0} to $+90^{0}$; Az. $\pm 270^{0}$

Observing System - Cassegrain or prime focus (feeds and secondary reflector are not a part of this contract)

Operational Frequency - 2.70 GHz (11 cm) and 8.09 GHz (3.7 cm)

Surface Accuracy - Installed RMS of 0.75 mm (0.030 in.) including manufacturing, alignment, gravity, operating wind and thermal errors under the specified precision operating conditions. Peak deviation from best fit paraboloid shall not exceed 2.2 mm (0.090 in.) under the specified precision operating conditions.

Panel Gap - 1.5 mm $\pm$ 0.5 mm (0.060 in. $\pm$ 0.020 in.)

Axis Alignment -

Azimuth axis to plane of telescope base plates - 18 arc seconds

Orthogonality azimuth to elevation - 18 arc seconds

Orthogonality reflector axis to elevation - 18 arc seconds

Focal axis to reflector - The structure at the apex of the feed legs must locate the center of the opening coincident within 0.1 in. and parallel within 30 arc seconds of the axis of the reflector. The deflection of the focal point prime focus from the best fit axis of the parabola when the antenna is moved from the zenith to horizon shall not exceed 1.5 mm (.060 in.).

Counterbalancing - Overbalanced to allow the antenna to return to zenith with no drive power under no wind, no ice, no snow conditions.

Drive Requirements - Azimuth and elevation drives shall have a capability of driving the antenna at a velocity of 20^{0} per minute with the reflector in any attitude under the specified operating conditions. Azimuth and elevation drives shall drive the antenna at sidereal tracking rates with an accuracy as specified.

Pointing Error

The pointing error is defined as the difference between the commanded position of the antenna and the position of the main beam of the reflector. The repeatable pointing error is due to gravity deformation, axis alignment error, encoder offset, bearing runout and similar errors. The non-repeatable pointing error is due to wind forces and gusts, acceleration forces, encoder resolution, servo and drive errors, and random errors.

The allowable repeatable pointing error for this antenna shall not exceed 3 minutes of arc. The allowable non-repeatable pointing error shall not exceed 15 seconds of arc RMS under operating conditions outlined below with the antenna in any attitude and while tracking a source at the specified tracking rates. The non-repeatable error contribution of the servo system shall be based on wind gusting 15 $\pm$ 3 miles/hour.

Slewing Motion

Slewing motion is defined as rapid movement of the antenna about either axis simultaneously or independently. The antenna shall be capable of driving at a rate of 20°/minute of time about the elevation and azimuth axis in winds to 45 mile/hour with the reflector in any attitude. It shall be possible to slew each axis independently while the other axis is stationary or moving at the tracking rate or to slew both axes simultaneously.

Tracking Motion

The antenna shall be capable of tracking a stellar source at the azimuth and elevation rates which correspond to the sidereal rate for the star position. The antenna shall be capable of azimuth and elevation accelerations of $0.25^{\circ}/\mathrm{sec}^2$. The cone of avoidance near the zenith when in the tracking mode shall have a half-angle less than 2.5°.

Operating Parameters and Conditions

General

The antenna will be exposed to the elements on a site 4000 feet above sea level. The antenna is to be designed for a life expectancy of 20 years. No damage to the operating components of the antenna must occur due to airborne sand or dust or accumulation of frozen or liquid water.

Requirements to be met for precision operation

Precision operation requires that the telescopes meet the surface and pointing accuracies stated above. Precision operation must be achieved under the following conditions:

Temperature range - -15° - $+80^{\circ}$F

Maximum temperature difference between any parts of the antenna structure - 5°F

Relative humidity - 0 - 50%

Rain rate - Maximum rate up to 0.2 in./hour

Ice or snow load - None

Wind (measured at 40-ft. elevation) - Up to 15 miles/hour with gusts of $\pm$ 3 miles per hour superimposed. Wind from any direction, reflector in any position.

Requirements to be met for normal operation

Normal operation means that the telescopes will continue to be fully operable, but with reduced (less than a factor of 2) pointing and surface accuracies. Normal operation must be possible under the following conditions:

Temperature range - $-22^{\circ}F$ to $123^{\circ}F$

Relative humidity - 0 - 98%

Rain rate - Maximum rate up to 2 in./hour

Ice or snow load - None

Wind (measured at 40-ft elevation) - Up to 40 miles/hour, with gusts of $\pm$ 5 miles/hour superimposed. Wind from any direction; reflector in any position.

Requirements to be met in moving to stow and in the stowed position

Slew to stow - The antenna shall be capable of being slewed to the stow position in winds of 60 miles/hour with all exposed surfaces of the structure coated with 1-cm radial thickness of ice. The slew rate may fall to 10°/minute.

Slew to dump snow - The antenna shall be capable of dumping snow by slewing at 20°/minute to any position 5° above the horizon with a wind of 25 miles/hour blowing from any direction and with an original uniform snow load in the reflector of 4 lbs/ft^2. No damage or overload shall occur to either structure or drives.

Survival - The antenna is to be designed to survive in the zenith position in winds of 110 miles/hour with 1 cm of radial ice on all exposed surfaces or when loaded with 20 lbs/ft^2 snow. When loaded under these conditions, yield stresses of materials shall not be exceeded and no permanent deformation shall occur. Stow brakes shall be provided capable of holding the antenna in the zenith position when subjected to the design survival loading.

All components of the antenna shall be properly designed for the loads and operating conditions to which they will be subjected. Design shall be based on a normal operating life of 20 years. The design shall provide adequate protection for all parts of the antenna against rain, dust, weathering and the accumulation of frozen or liquid water. The entire pedestal shall be environmentally protected. Blowers shall be provided to cool motors and ventilate pedestal housing if required.

Structural and Mechanical Features

Reflector Assembly

Surface - The reflecting surface shall be a paraboloid of revolution comprised of individually adjustable, double curved, solid surface aluminum panels. The spacing between panels shall be nominally 1.5 mm (0.060 in.) with a tolerance of 0.5 mm (0.020 in.). The installed RMS deviation of the surface from a best fit paraboloid shall not exceed 0.75 mm (0.030 in.) including manufacturing, installation and alignment, gravity, and thermal errors with the antenna in any operating attitude and with winds not exceeding 18 miles/hour. An error budget shall be prepared showing distribution and projected levels of each error contribution.

Panels shall be designed to withstand either a 20 lbs./ft^2 uniform load or a concentrated load of 250 lbs. over a 6 inch square area located at any point without exceeding the allowable design stresses for the material.

Manufacturing accuracy of 90% of the individual panels to be .012 inches RMS, with no panel to exceed .015 inches RMS, as determined by measurement of a representative number of points with reference to the design parabola passing through panel corner points as control points. Each individual panel shall be permanently marked numerically or alphabetically at a location easily viewable from top of panel. Each panel shall have an individual log prepared by Vendor showing history of assembly such as date of assembly, date of tests, temperature at tests, weight, dimensions (periphery, diagonal and elevation) and measured RMS.

Control points for adjustment shall be permanently located on reflector surface of each panel at or near its adjustment mechanism to be used during the acceptance test and for final setting of the panels on the telescope. The control points shall be such that they are viewable from the vertex and shall be specific points on the design parabola. The number of points measured on each panel shall be such that each point represents approximately 120 square inches of area. Wind effects on the antenna at any operating attitude in winds up to 25 mph shall not degrade the reflector to more than .032 inches RMS.

<u>Feed Legs and Apex</u> - The feed leg supports shall be designed to support either an adjustable feed support system weighing approximately 800 lbs. and a prime focus feed of approximately the same weight, a total of 1600 lbs. The feed legs shall also be designed to support a cable weight of 8 lbs. per foot on each leg.

The apex structure shall be so designed that a clearance of 18 to 24 in. (with 20 in. preferred) exists between the bottom of the apex structure and the focal point of the main reflector. Its configuration shall be such that an opening of approximately 48 in. diameter exists on the centerline of symmetry for the location and attachment of adjustment mechanism and support of the prime focus feed. Requirements for the mounting of the adjustment mechanism will be provided by AUI at the time of manufacturing. The feed legs and apex structure, including the prime focus feed shall not cause RF blockage in excess of 6 percent of the total aperture area.

Back-up Structure - The reflector back-up structure shall provide the rigidity required to achieve the specified reflector tolerance and shall be designed so as to achieve the highest practical stiffness to weight ratio.

Panel Supports - Each surface panel shall be supported at a minimum of four points by means which will allow field adjustment. The panel supports shall be designed to allow one 250 pound man to walk on the panel without causing permanent deformation.

Antenna Pedestal

Structure - The pedestal structure shall be designed to provide the stiffness and strength required to meet the operating and survival requirements and to provide the range of motion as specified. Components of the pedestal structure shall be designed to facilitate field erection and assembly to the required tolerances. Field assembly shall preferably be by use of high strength bolting. Adjustment provisions shall be provided for alignment of bearings, gear racks and supported drives and gear boxes. The antennas shall be so designed and erected that the azimuth and elevation axes intersect and are orthogonal within the tolerances specified. The axis of symmetry of the paraboloid shall intersect the elevation and aximuth axes and shall be orthogonal to the elevation axis within the tolerance specified. Appropriate openings and guides shall be provided to protect the signal and control cables. AUI will advise of the number and size of cables and recommended routing.

Drive Equipment - Electrical drives using DC servo motors are the preferred drive system for each axis. The drive systems shall be supplied in pairs and torque biasing shall be provided so that paired gear trains oppose each other during operational function so as to minimize backlash. Motors selected shall have a base speed not to exceed 1750 RPM. The drive motors shall be able to withstand the following current load conditions:

100% rated	continuous
150% rated	2 minutes out of every 20 minutes
200% rated	instantaneous, 0.5 seconds, repeated once every minute.

The reducer ratio from motor to antenna axis shall be sized to deliver the torque required and to meet the speed requirement. All enclosed gearing shall be lubricated with oil or run in an oil bath and shall be heavy duty class III gearing.

Brakes - Brakes that actuate with the power off shall be provided on each axis. Brakes on each axis shall have the capacity of three times rated motor torque. Brakes must have the capacity to hold the antenna in any position in winds to 60 miles/hour and to hold the antenna in the stow position in winds to 110 miles/hour.

Brakes may be provided in either of two configurations:

Operating brakes mounted on the motors and braking through the gear train plus stow brakes which act on the main section gear. This is the preferred configuration.

Brakes which serve both as operating and stow brakes which operate through the gear train.

Remotely controlled stow locking devices, such as stow pins, shall not be used as an operating feature.

A manually operated stow pin shall be provided on the elevation axis for use in maintenance.

Bearing and Gears - All main axis bearings and power train gearing shall be conservatively designed with a minimum 20 year expected life period. Running friction and breakaway friction for the drive system shall be held to levels which satisfy the non-repeatable pointing error budget.

Cable Wraps - Access shall be provided at the azimuth axis in the form of a cable wrap through the axis which will accommodate a minimum of 20 cables of 1.5 in. in diameter with connectors of 3 in. outside diameter. Arrangement shall be such that cables are neither stressed by twisting or damaged by pulling over edges of fixed structure. Cables may pass the elevation axis by means of a cable loop.

Lubrication - Provision shall be made in the design for proper lubrication of all components. Gear boxes, gear trains, couplings, bearings, motors and similar equipment provided by the Subcontractor shall have easily accessible lubrication fittings, drain fittings and be provided with vents where advisable. The design Subcontractor shall prepare a list of recommended lubricants and lubrication schedule. Lubricants shall be adequate to meet the performance and environmental requirements specified herein. The use of different types of lubricants and the frequency of lubrication shall be held to a minimum.

Grounding - The antenna requires safety and equipment grounds. A station ground will be provided by AUI for the antenna structure. The Subcontractor shall ground the antenna structure, and its equipment, in accordance with National Electrical Code Specifications to this station ground. All bearings shall have a by-pass grounding connection.

Miscellaneous Requirements

All operating components of the antennas, such as motors, bearings, drive units, brakes, gear boxes, switches, breakers, etc., shall to the extent possible be of standard design, and proven operating life.

Access ladders, walkways and platforms for service, access and maintenance to bearings, motors, and drives and all equipment shall be designed according to best antenna practice, shall meet the requirements of the Occupational Safety and Health Act and shall have sufficient strength to support at least a concentrated load of 400 lbs. at any point.

Safety devices shall be provided for protection of the antenna in the event of servo or mechanical failure, consisting of mechanical stops and bumpers or shock absorbers.

Limit switches shall be provided for each axis of the antenna.

All machinery shall be covered or protected in such a way that working personnel are not subject to hazards.

Limit switches, cables, connectors used on telescope drives, brakes, motors, gear boxes, interlocks, etc., are to be weather-tight.

Foundations

The Subcontractor shall provide the design of a typical foundation. Final design and detailing of the foundations and construction of these foundations will not be the responsibility of the Subcontractor but the Subcontractor shall supply all data needed to design the foundations to provide the stiffness and the pointing accuracy required.

Control System

Control and pointing of the antenna will be by AUI, using a computer to convert from polar coordinates to the telescope coordinates.

The antenna subcontractor shall supply all necessary parameters for the design of the servo control system, including load inertias, motor characteristics and gear train data. The provision of this servo system is not a part of this contract.

Provision shall be made in the design for mounting of direct drive shaft angle readout equipment. The elevation and azimuth axes of the antenna shall be equipped with these mountings. Requirements for these systems will be provided by AUI at time of manufacturing the antenna . The furnishing of these readout systems and their associated readouts and connection to servo system or computer is not a part of this contract. The position indication will be by inductosyns.

Erection

The antenna shall be finally erected, on foundations provided by AUI, on its permanent site near Monterville, West Virgina. The site is located just off paved State Route 15. An access road capable of handling tractor trailers and cranes needed for erection, will be provided to the site by AUI. Storage space will be available at the site for equipment and materials. The Subcontractor shall furnish all materials, plant and equipment, tools and all labor, services and supervision necessary to complete the erection, assembly, alignment and testing of the antenna.

The antenna shall be completely assemblied, at the subcontractor's plant, before shipment to the site for the permanent installation.

Protective Coatings and Finishes

The reflector surface of the antenna shall receive a protective coating which will provide diffuse reflection of the solar rays. Material, preparation, application and quality control testing shall be as set forth in National Radio Astronomy Observatory Process Specification dated August 30, 1972, entitled "Application of Diffuse

Reflecting Coating for Solid Faced Antenna Reflectors", attached hereto.

To limit the effect of solar heating and associated differential expansion of structural members and to protect the structure against atmospheric corrosion, the antenna structure, with the exception of the reflecting surface, shall be painted with a white solar reflecting paint. Material, preparation, application and quality control testing shall be as set forth in National Radio Astronomy Observatory Process Specification dated August 30, 1972, entitled "Exterior Protective Coating for all Exposed Metalic Surfaces other than Reflector Surfaces", attached hereto.

Engineering, Design and Shop Drawings

One reproducible copy of engineering, design and detailed drawings of all components and assemblies and any working drawings which the subcontractor may require to detail or illustrate any part of the work, supplementing the information in this Job Specification, shall be furnished at no additional cost to AUI. Such working drawings shall be consistent with the purpose and intent of the Job Specification, and shall be subject to approval of AUI's Engineer. Approval will be granted within five days of receipt of drawings and if not approved, the reason for non-approval will be specified. AUI approval of the drawings will be granted unless it can be demonstrated that the subcontractor's drawings are contrary to a provision of the specification. AUI will recognize these drawings as in some instances containing proprietary information and agrees not to submit these drawings to outside concerns or to use them in any fashion which might adversely affect the subcontractor's position.

Detail drawings, sketches, specifications and purchase orders of all purchased manufactured components shall, to the extent that this data is made available by vendors (a) without increase in the price of the purchased components and (b) without limitation on further distribution by subcontractor, be submitted by the subcontractor to AUI prior to manufacture or assembly of the antenna. This submittal shall be for information only. Pricing data appearing on purchase orders may be deleted.

All drawings, specifications, purchase orders and other pertinent papers submitted by subcontractor of its vendors pursuant to this contract may be used by AUI only for the (1) repair and maintenance of this antenna system and (2) replacement of purchased manufactured components direct from the original source.

In the performance of the work, the subcontractor shall submit monthly reports to AUI on the progress of the work, shall secure AUI approval of the concepts of the design as the work progresses, and shall make such changes to the design as AUI and the subcontractor shall jointly agree upon. AUI approval of the design will be granted unless it can be demonstrated that the subcontractor's design is contrary to a provision of the specification. Approval or disapproval will be granted within five (5) days after receipt by AUI, and if not approved, the reason for disapproval will be stated.

Inspection and Acceptance

AUI may inspect or test any component or assembly, either visually, optically, manually or mechanically during or after fabrication at the site of fabrication or wherever fabricated or assembled.

Quality assurance tests shall be performed by the subcontractor or his subcontractors on the various components of the antenna. AUI will identify to the subcontractor such tests as it desires to witness and shall be notified by the subcontractor prior to the performance of these tests. Test facilities shall be provided by the subcontractor. Subcontractor shall submit during the design stage a recommended Quality Assurance plan for AUI approval.

Final acceptance will be after final erection and testing at the permanent site.

Special Tooling

Any special tooling which has been fabricated, purchased or otherwise received, and whose total cost has been charged to this job and whose function is unique to the job, shall become the property of AUI after completion of the work specified herein. Optical tools, clinometers, levels theodolites, and similar tooling which are not purchased specifically for this job, and whose purchase price was not included in the proposal price, are excepted from this requirement.

Operation and Maintenance Manuals

The antenna subcontractor shall deliver at the time of final testing of the antenna four (4) copies of an Operation and Maintenance Manual. This Operation and Maintenance Manual shall contain the following information:

Manufacturer's drawings, exploded view assembly drawings, parts lists and recommended lubrication procedures for all purchased mechanical components. Manufacturer's drawings, parts lists, specifications, wiring diagrams and testing procedures for all purchased electrical or electronic components. A lubrication schedule showing lubrication points, types of lubrication and recommended lubricant, frequency of lubrication.

A maintenance section which describes method of removal of mechanical components, methods and control to be used in re-assembly and re-alignment and components which might reasonably be expected to be replaced because of wear characteristics. Assembly and sub-assembly drawings which include mechanical setting dimensions such as bearing pre-loads, year runouts, gear backlash settings, torque bias settings, drive train alignment requirements and weight of components.

MICROWAVE LINK PATH INVESTIGATION

We have investigated a number of possible microwave link paths by searching topographic maps, plotting terrain profiles, and computing path losses. The best path appears to be from the Monterville site to a 4,757-foot peak on Back Allegheny Mountain and from there to Asbury Knob and then to the control building. A double passive reflector is required on the 4,757-foot peak and a single passive reflector on Asbury Knob as shown in Figure 1. The plotted profiles taken from the topographical maps show adequate path clearance. We still want to check path clearance visually using a mirror or light as soon as the weather conditions permit. However, we are sure enough of this path to use it for our planning and cost estimates.

Path Clearance Requirements

The microwave beam travels across the surface of the earth following a path of 4/3 earth radius under normal atmospheric conditions. This bending is caused by the denser parts of the atmosphere slowing the lower portion of the microwave beam in relation to the upper part.

If part of the microwave beam travels a path that is longer than the direct path, it could arrive at the antenna out of phase with the direct wave and reduce the received signal. The zone where the indirect path is one half wavelength longer is defined as the first Fresnel Zone.

To assure adequate clearance for reliable microwave transmission, the plotted path should clear all obstructions by 1.0 Fresnel Zone radius at 4/3 earth radius or 0.3 Fresnel Zone radius at 2/3 earth radius. Using these guidelines, the path clearance required in the middle of the 14-mile link would be 60 feet. Forty feet clearance is required at 3.9 miles on the 7.8 mile path. The clearance requirement is reduced near the ends of the paths. The Fresnel Zone radii were computed for a 16 GHz frequency link. Higher frequencies would require slightly smaller path clearances.

Path Loss Calculations

The general method for computing path loss is to compute the sum of the losses in decibels for each leg of the microwave link path, determine the gains for each of the passive reflectors and the transmitting and receiver antennas and take the difference as the overall path loss. The losses and gains are tabulated below for a link frequency of 16 GHz.

14 mile path loss Monterville to 4,757 ft. peak	143.5dB
7.8 mile path loss 4,757 ft. peak to Asbury Knob	138.4dB
2.2 mile path loss Asbury Knob to Control Bldg.	127.4dB
Total Path Loss	409.3dB

The passive reflector gain depends on the projected area of the reflector perpendicular to the microwave beam. The 10' x 16' double passive reflectors on the 4,757 foot peak, give a gain of 111 to 114 dB depending on the distance between the reflectors. The passive reflector on Asbury Knob would have a gain of 114 dB.

If six-foot diameter, parabolic antennas are used at Monterville and the control building, a gain of 47 dB for each or 94 dB would result.

The total gains for the reflectors and antennas would be:

Double 10 x 16 Passive Reflector	111 dB	worst cast
Single 10 x 16 Passive Reflector	114 dB	
2 six-foot diameter antennas	94 dB	
Total Reflector & Antenna Gain	319 dB	
Total Path Loss	409 dB	
Total Reflector & Antenna Gain	- 319 dB	
OVERALL PATH LOSS	90 dB	

Signal-to-Noise Ratio

From the overall path loss, the receiver sensitivity and the transmitter power the signal-to-noise ratio can be calculated. The noise level referred to the input of the receiver with no signals present is about -93 dBm. The transmitter power in a 30 MHz band would be 0.5 watts or +27 dBm at the antenna. The received power with 3dB waveguide loss would be +27 - 90 - 3 or - 66 dBm. The signal-to-noise ratio in a 30 MHz band would be 27 dB which is the difference between the receiver noise and the received signal.

Fading Margin

A microwave transmission system will experience signal attenuation in excess of the predicted losses during abnormal atmospheric conditions. The amount of extra loss that can be tolerated is called the fading margin. A signal-to-noise ratio of 17 dB would be adequate for the radiometer signals. At this level 2% of the power in the 30 MHz band would be contributed by the microwave link. The fade margin for the proposed link would be 10 dB. Over the rough mountainous terrain the probability of severe fading is reduced.

It is expected that each link would experience fading in excess of 10 db only for about 3 hours during each year.

Rainfall Attenuation

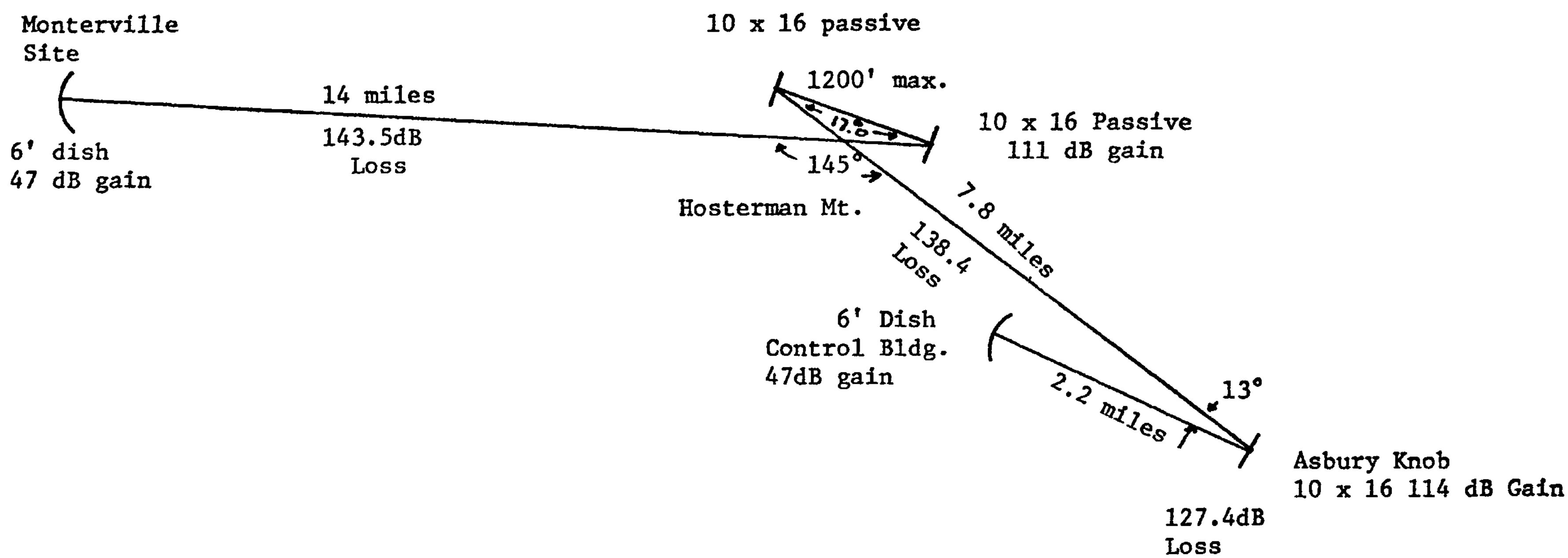
At 16 MHz the extra attenuation caused by a heavy rain (.64 inch per hour) would be about 1 dB per kilometer. If the rain was occurring over the full path, then the extra attenuation would be forty dB and the link would fail. It should operate in a moderate rain (.16 inch per hour) as this would cause about 8 dB extra attenuation.

Multipath fading should not occur during rainstorms so the full 10 dB margin would be available to compensate for the extra rainfall attenuation.

Summary

The proposed link design should provide satisfactory operation. If it is determined that a greater signal-to-noise ratio is required, the diameters of the parabolic antennas at each end could be increased. If 10-foot diameter paraboloids are used, the extra gain would be 9 dB. Increasing the size of the passive reflectors is probably not desirable. The 10 x 16' reflector would have a half-power beamwidth of 0.2° at 16 GHz. The 10-foot paraboloid has a beamwidth of 0.44°. The narrower the beamwidth, the more rigid the supporting structures must be to prevent wind loads from deflecting the reflectors.

Figure 1. Monterville Site to Control Bldg. Microwave



16 GHz path loss 90 dB

C5

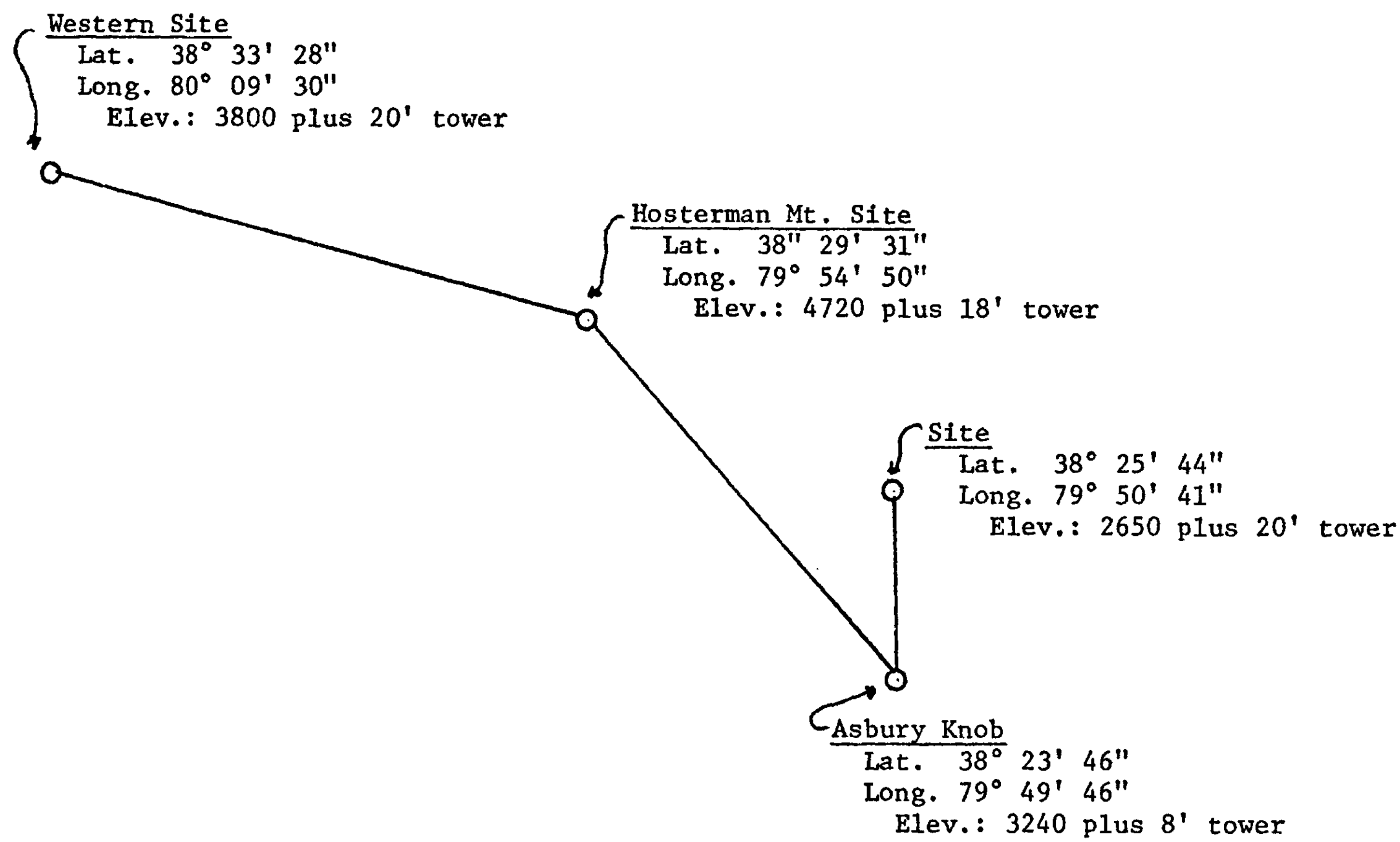
J. Coe
1/18/70

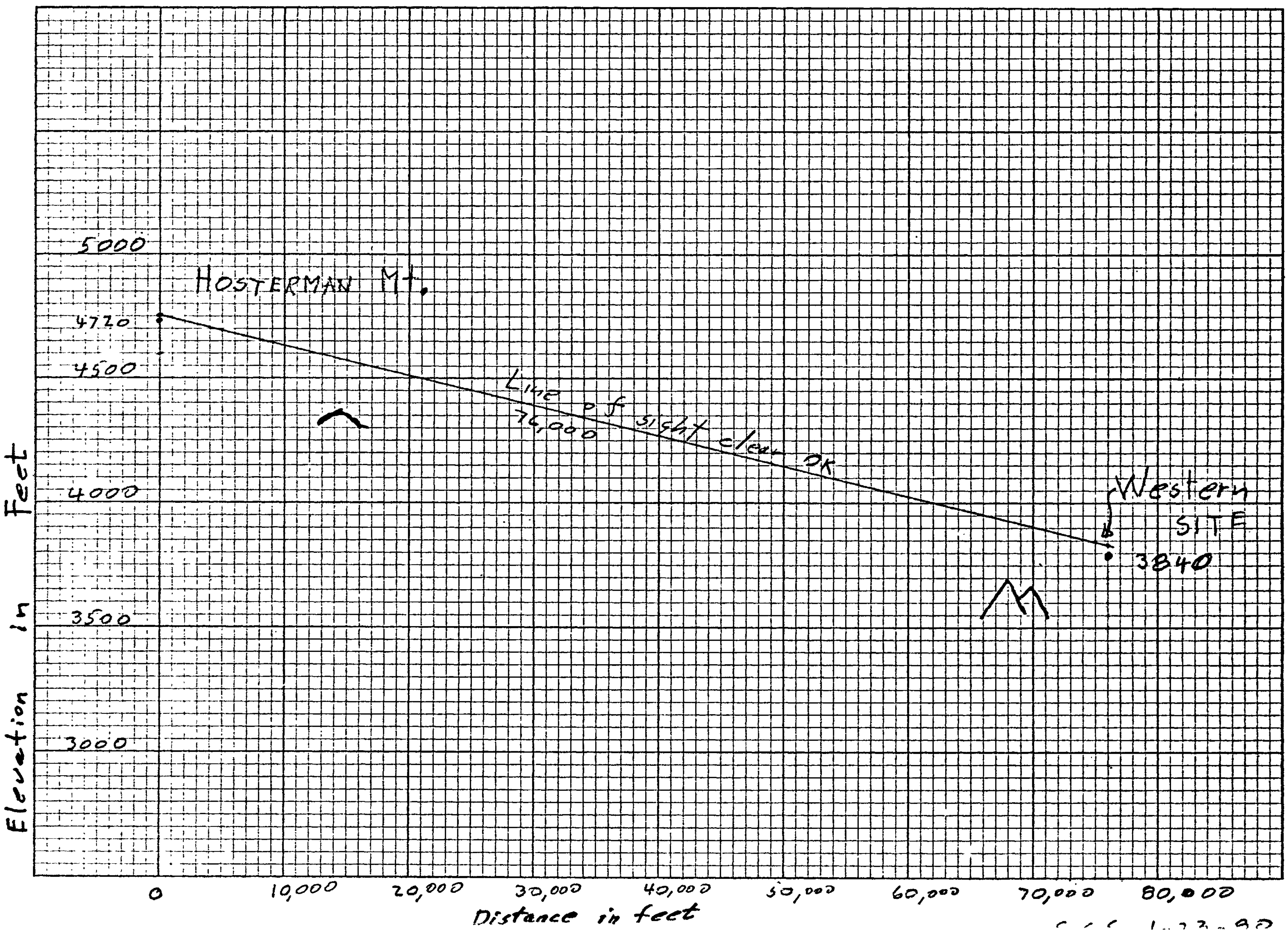
2/04/80

MEMO TO: J. Coe

FROM: S. C. Smith

SUBJECT: Passive Repeater Line No. 3 Rev. A

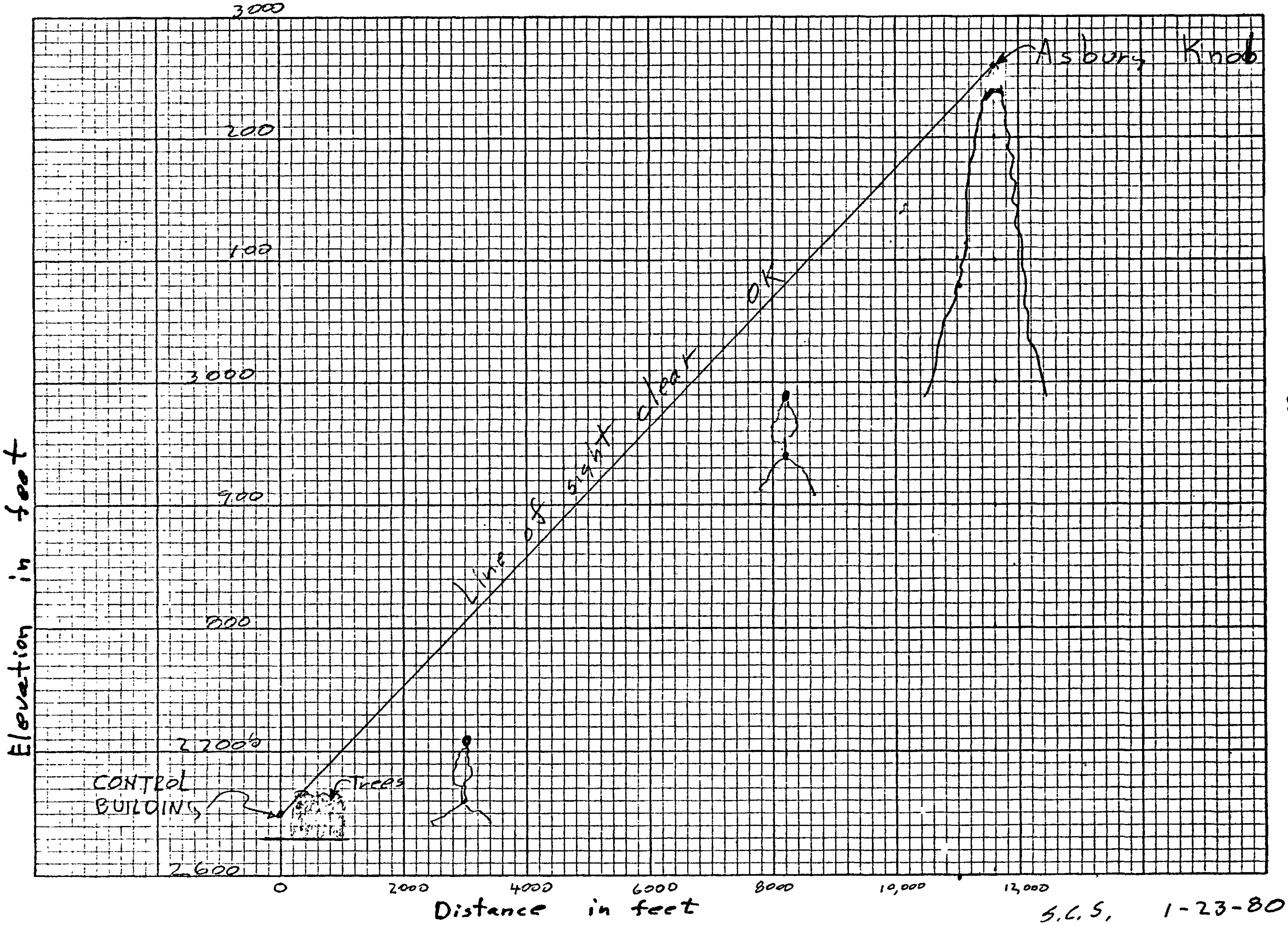



HOSTERMAN Mt.
5000
4720
4500
4000
3500
3000
Line of sight clear OK
76,000
Western
SITE
3840
Elevation in Feet
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Distance in feet


HOSTERMAN Mt.
5000
4720
4500
4000
3500
3000
Elevation in feet
Line of sight clear ok
41,000 feet
Asbury Knob
0
5000
10,000
15,000
20,000
25,000
30,000
35,000
4000
Distance in feet

S.C.S. 1-23-80

C8



3000
200
100
3000
900
800
2200
2600
0
2000
4000
6000
8000
10,000
12,000
Asbury Knob
Line of sight clear OK
CONTROL BUILDING
Trees
Elevation in feet
Distance in feet
S.C.S. 1-23-80

NATIONAL RADIO ASTRONOMY OBSERVATORY
EDGEMONT ROAD
CHARLOTTESVILLE, VIRGINIA 22901
TELEPHONE 804-296-0211 TWX 510-587-5482

ADDITIONAL BASELINE TO INTERFEROMETER
MEMO No. 124

May 13, 1980

Captain Raymond A. Vohden, Superintendent
U. S. Naval Observatory
34th and Massachusetts Avenue, NW
Washington, D. C. 20390

Dear Captain Vohden:

We have completed the study you requested for adding a new east-west baseline to the Green Bank interferometer. A copy of this study is enclosed.

The estimated cost for the project is about $1.6 million, with a three year completion time, using either a modified 85-ft telescope or acquiring a new 40-45 ft telescope for the new baseline. However, using one of the existing 85-ft telescopes would be considerably more expensive to operate and maintain than a new telescope would be--by a factor of 2.5-3.0. Assuming a 5-year operational period, the estimated cost differential would be about $300k greater for an 85-ft telescope. Consequently, we suggest that a new telescope be acquired.

We do not believe that an Environmental Impact Statement will be required for this project. However, it will be necessary that the principal funding agency for which the work is to be done concurs with our opinion on this matter and notifies us accordingly. Since the work is to be done <u>for</u> the U.S. Naval Observatory but the funds will flow <u>through</u> the National Science Foundation, we assume that either agency can supply us with the necessary documents.

Sincerely yours,

Morton S. Roberts
Director

cc: W. E. Howard
G. Westerhout

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TWX 710-938-1530

OPERATED BY ASSOCIATED UNIVERSITIES, INC. UNDER CONTRACT WITH THE NATIONAL SCIENCE FOUNDATION

NRAO STUDY OF AN ADDITIONAL EAST-WEST BASELINE

TO THE NRAO INTERFEREOMETER

May 13, 1980

General

A study of the tasks and probable costs involved in upgrading the Green Bank interferometer for radio astrometry by adding an orthogonal baseline has been completed. The principal results of this study are:

1. That a new 12 to 15-meter telescope be purchased which is similar in design to the existing 45-foot telescope currently used with the NRAO interferometer;
2. That a suitable and available site has been located which meets the requirements for baseline length and orientation;
3. That a microwave link will be used to transmit radiometer outputs and telescope positions from the remote site to the interferometer; and
4. That the existing interferometer control computer be retained.

Telescope

The purchase of a new 12-15 meter diameter antenna is the best solution for providing a reliable remotely operated telescope for the baseline extension. The existing NRAO 85-foot antennas require significantly more expenditure of both manpower and materials for operation and maintenance than does a new antenna. Operational cost comparisons are shown as Item 6 of the attached Budget Estimate.

Specifications for a new antenna are given in Appendix B. A summary of these specifications were sent to 32 prospective suppliers for an expression of interest in engineering and fabrication of the antenna. Four responded affirmatively.[1]

Site

A telescope site near Monterville, Randolph County, West Virginia, has been located which meets the projects needs. The coordinates are 38° 33' 28" latitude, 80° 09' 30" longitude, with an elevation of 1183 meters above sea level. The baseline length from 85-1 to this site is 31.8 km at an azimuth of 295.3°. Preliminary discussion with the property owner indicates he is willing to lease the site.

The site includes a concrete foundation for the telescope, a telescope service elevator and pad. A standby generator capable of stowing the telescope and fuel storage for the generator, an electronic equipment shelter which is temperature controlled and a shelter for service personnel will also be required. The budget estimate for site preparation and construction is shown as Item 1 in the Budget Estimate.

A preliminary plan for the site is shown in Appendix A.

Link

A two-way microwave link will be required to provide a phase-stable local oscillator signal to the remote site; to transmit two 30 MHz

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1. The four companies did not indicate any costs. The cost estimate shown in the cost table ($735,000) is NRAO's.

wideband radiometer outputs to the interferometer control building; and to transmit antenna control and antenna position information to and from the remote site. The microwave links will operate in the 16 to 18 GHz frequency band. A study has been made of possible microwave link paths between the remote site and the interferometer control building. Adequate signal levels can be obtained by using passive reflectors to obtain the required path clearance as shown in Appendix C. The budget estimate for installing a new microwave link and upgrading the existing link is shown as Item 3 in the Budget Estimate.

Computer

The existing control and data acquisition computer should be retained. This computer can be used to operate the expanded four-element interferometer with a minimum of hardware and programming changes. Two new hardware ports would be added to interface with the new antenna link and the proposed data analysis computer.[1] The cost of implementing these ports is included in the link budget figures. Programming changes would require approximately 13 man-weeks of programming. This cost is included in Item 4 of the Budget Estimate.

The NRAO does not have anyone available to do this programming. Additionally, there is presently no programming support for the existing interferometer software, and this increases the time required to restore

1. The data analysis computer is not a part of this study.

the system to an operating condition when a malfunction stops the computer. Lack of programming support prohibits even minor changes or corrections to the computer program. One possible solution would be for the Naval Observatory to provide a programmer to make the necessary program changes and provide documentation of the complete program, and also train one or more NRAO employees in program diagnostics.

Personnel Requirements and Time Schedules

We believe the project can be completed over a three-year period using existing NRAO personnel provided that U.S.N.O. funds can be committed to the project at the outset. As a minimum, approximately $1.0 million will be required at the beginning of the first year in order that contracts can be awarded for long-lead items such as the telescope, electronics, etc.

Attachments: Budget Estimate
Appendices A, B and C

05/13/80

BUDGET ESTIMATE*

	85-ft Telescope		New Telescope	
1. Site Preparation				
Contracts and Materials	$ 82.8		$ 82.8	
Labor and Overhead	42.0	$ 124.8	40.8	$ 123.6
2. Telescope				
Contracts and Materials:				
Foundation	$ 45.0		$ 9.0	
New Telescope			735.0	
Relocate 85-ft Telescope	500.0			
85-ft Drives	130.0			
Drive and Control System	75.0		25.0	
Focus and Feed Mount			45.8	
Cables, Instrumentation	9.0		7.7	
Power and Control			7.0	
Painting Telescope	25.0			
Other	10.8		10.8	
Labor and Overhead	119.8	$ 914.6	87.3	$ 927.6
3. Microwave Link				
Contracts and Materials	$147.0		$147.0	
Labor and Overhead	112.3	$ 259.3	112.3	$ 259.3
4. Computer				
Contracts and Materials	-		-	
Labor and Overhead	$ 11.3	$ 11.3	$ 11.3	$ 11.3
5. Freight, Leases, Utilities during Construction				
Contracts and Materials	$ 36.0		$ 36.0	
Labor and Overhead	-	$ 36.0	-	$ 36.0
Total Estimated Cost		$1,346.0		$1,357.8
Contingency @ 15%		202.0		203.2
Total Budget Estimate		$1,548.0		$1,561.0
6. Estimated 5 year Operating Cost**		$ 510.0		$ 195.0

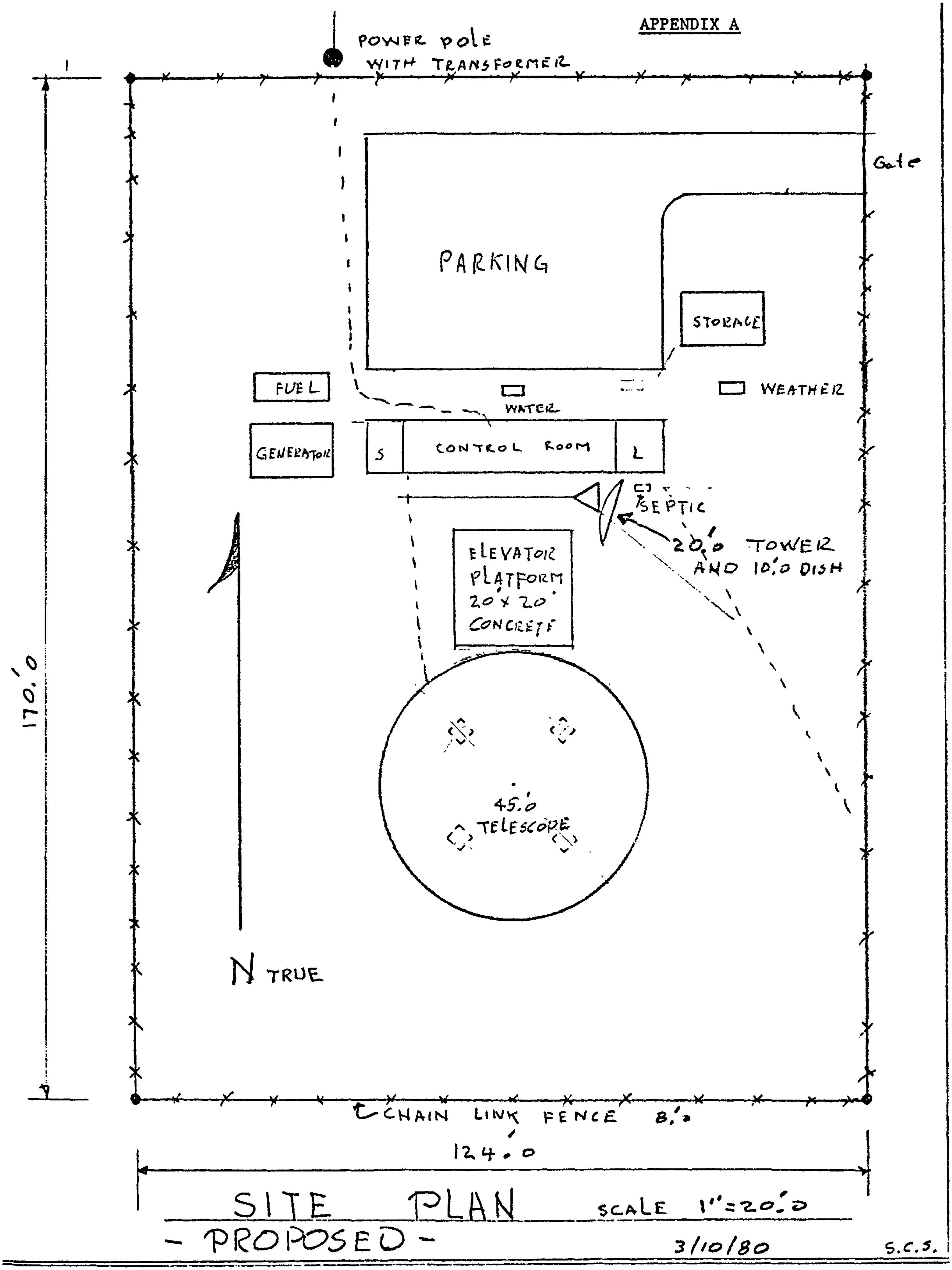
* Estimate in current (March 1980) dollars. No provision has been made for price escalation over the life of the project.

**Additional cost for the new baseline only. Must be added to present (base) operating costs.

	Months																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	3
TE																																				
Acquire property	x																																			
Finalize site design		x																																		
Install utilities						x																														
Install foundations								x																												
Facilities:																																				
Concrete pads								x																												
Roads									x																											
Security fence									x																											
Equipment housing											x																									
Landscaping												x																								
Install electronics equip.																																	x			
ELESCOPE																																				
Finalize specifications	x																																			
Request quotations	x																																			
Award contract			x																																	
Delivery															x																					
Commence erection																x																				
Adjustment																	x																			
Purchase telescope accessories													x																							
Delivery telescope accessories																					x															
Install cables																						x														
Install other acc.																															x					
Test																																			x	
INK																																				
Acquire property	x																																			
Complete design new baseline												x																								
Complete design 85-1, 45-ft. upgrade												x																								
Order materials													x																							
Materials delivered																		x																		
Install reflectors																												x								
Complete elect. assy																												x								
Test electronics																													x							
Complete installation																															x					
INAL TEST & CALIBRATION																																				>

Notes: 1. Dates indicate commencement of project(s) unless specified otherwise.
2. Length of time for completion of projects are subject to availability of resources and are not specifically predicable on this chart.

APPENDIX A


POWER POLE
WITH TRANSFORMER
Gate
PARKING
STORAGE
FUEL
WATER
WEATHER
GENERATOR
S
CONTROL ROOM
L
SEPTIC
20.0' TOWER
AND 10.0' DISH
ELEVATOR
PLATFORM
20' x 20'
CONCRETE
45.0'
TELESCOPE
N TRUE
170.0'
CHAIN LINK FENCE 8.0'
124.0'
SITE PLAN
SCALE 1" = 20.0'
- PROPOSED -
3/10/80
S.C.S.