VLB ARRAY MEMO No. 2

ANTENNAS FOR THE VLBI ARRAY

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1. Introduction

The purpose of this note is to try to give the performance specification for a 25-meter diameter antenna which would fully satisfy the needs of the VLBI array and not be too expensive nor too difficult to build.

When the performance specification is clear, it can be used to ask:

(a) What existing antennas have a performance which approaches, or equals, the specified performance

(b) What sort of engineering and costs might be involved in upgrading existing antennas?

(c) If the cost differential seems large, should this present performance specification be somewhat downgraded? If so, where, and to what extent?

2. A Specification

(a) General

The following specification is derived from a much-condensed version of the VLA antenna specification, as given in the original RFP-VLA-01 and in subsequent modifications to that document. It is assumed that the Az-El antenna is the correct choice. The VLA performance specifications have been upgraded in several places. The environmental effects paragraph is written as if the antenna were fully exposed. Perhaps, however, some thought should be given at the early stages to a radome-enclosed antenna for use at sites with high winds. Much of the rather formal material in RFP-VLA-01 has been omitted. If it becomes needed, it can be used at a later stage.

(b) The Antenna Design

(i) The antenna may resemble one of at least two concepts--the VLA antenna which is a "king-post" design or a "wheel and track" antenna. Either concept would be acceptable in the VLBI array design.

(ii) The antenna will be one of about 10 identical antennas situated on various sites in North America. The climatic conditions at the various sites will be different. However, in defining the environment, possible conditions at most sites have been included.

(iii) The antenna shall be an elevation over azimuth configuration with a 25-meter diameter solid surface of revolution as the main reflector. The observing system to be used shall be both Cassegrain and prime focus. Use of a Cassegrain observing system shall be considered the normal mode of operation, but provision for removal of the secondary reflector and installation of a receiver for operating as a prime focus instrument will require a clear opening of approximately 4 feet diameter at the apex of the feed legs symmetrical about the reflector axis. (See paragraph 3(a) for details.)

(c) Mechanical parameters

Diameter - 25 meters

Focal length - 9 meters

f/D - 0.36

Sky coverage - Elevation +5° to 125°

Azimuth ± 270°

Observing System - Cassegrain or prime focus.

The reflector system will be "shaped" so that increased aperture efficiency in the Cassegrain mode will result. The highest frequency to be used in the prime focus mode will be 800 MHz and the main reflector shaping will not be so severe as to prevent this use.

Operational Frequencies -

Cassegrain mode - 1.35 GHz to 43 GHz

Prime focus mode - Up to 800 MHz

Reflector - The reflecting surface shall be a surface of revolution composed of individually adjustable, doubly curved solid surface aluminum panels. These panels must withstand either a 20 lb/sq. ft uniform load or a concentrated load of 250 lb over a 6 inch square.

Panel Gap - The spacing between panels shall be nominally 2.0 mm with a tolerance of 0.75 mm.

Axis Alignment -

Azimuth axis to plane of telescope base -18 arc seconds

Orthogonality azimuth to elevation -18 arc seconds

Orthogonality reflector axis to elevation - 18 arc seconds

Subreflector axis to reflector - alignment of the subreflector will be accomplished by an AUI furnished adjustable mounting mechanism. The structure at the apex of the feed legs must, however, locate the center of the opening coincident within 0.1 inch and the axis of the opening parallel within 30 arc seconds to the axis of the reflector.

Counterbalance - 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 80° per minute in azimuth and 20° per minute in elevation, 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 in paragraph 2(e)(ii) below.

(d) Operating conditions

General - The antennas will be exposed to the elements at various sites, some of which may be as high as 8000 feet above mean sea level. The antennas are to be designed for a life expectancy of 20 years. No damage to the operating components of the antennas must occur due to airborne sand or dust or accumulation of frozen or liquid water. It is expected that the antennas will be operated remotely for periods of a few hours. There may be no one in attendance during such periods.

Precision operating conditions (POC) - The antenna must give its specified POC performance when the environment and the telescope structure are no more harmful to precision operation than the following:

Ambient air temperature lies in the range -10° C to +25° C.

The rate of change of ambient air temperature is no greater than ± 2° C per hour.

No parts of the telescope structure differ in temperature by more than 2.5° C.

The relative humidity is between 0 and 50%.

The wind at 12 m elevation is no greater than 6 m/sec, with gusts no greater than ± 1 m/sec superimposed.

There is no snow load, no ice and no rainfall.

Normal operating conditions (NOC)

The antenna must continue to operate under "normal" operating conditions. The performance to be expected under these conditions will be less accurate than under POC. The required performance is not specified for NOC since experience shows that, if POC performance is met, NOC performance is acceptable. Normal operating conditions are defined as:

Ambient air temperature -30° C to +40° C.

Relative humidity 0 to 98%.

Rain rate - no greater than 5 cm/hour.

Ice and snow load - none.

Wind at 12 m elevation, 18 m/sec with gusts of ± 3 m/sec superimposed.

Moving to stow and in the stow 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.

(e) The antenna performance

(i) Surface accuracy. Under the precision operating conditions (specified in 2(d) above), the RMS of the best-fit reflector surface shall be no greater than 0.45 mm. Under these same conditions the peak deviation of the surface from the best-fit surface shall not exceed 1.5 mm.

(ii) Pointing errors. 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 nonrepeatable pointing error is due to wind forces and gusts, acceleration forces, effects of temperature differences and temperature changes, encoder resolution, servo and drive errors, and random errors.
The repeatable pointing error for this antenna shall not exceed 3 minutes of arc.
The nonrepeatable pointing error is divided into two types of error with different statistical behaviour.

The first type of nonrepeatable errors behaves correctly, in a statistical sense, with errors changing in magnitude and sense within times of up to a minute. Such errors average out fairly well in observations taken over several minutes. Nonrepeating errors of this type, under the precision operating conditions (see 2(d) above) shall not exceed 7 arc seconds. This figure shall be derived by making the RSS of all error contributions with the antenna in any attitude and while tracking a source at the specified tracking rates. The values of individual errors which contribute to the RRS error budget should be RMS values wherever these can be determined. It may only be possible in some cases, such as the wind-induced distortions of the reflector, yoke, alidade and tower, to identify the reflector attitude and wind direction which gives the greatest error (the "worst case"). One half of such "worst case" error values should be used in the RRS error budget.

The second type of nonrepeatable pointing error is that which usually results from thermally induced distortions of the antenna structure. These errors have time constants typical of the times over which serious temperature changes or temperature differences occur. These times may lie between several minutes and a few hours.

It is possible to reduce the effects of such errors on the pointing by thermal control, thermal insulation or by measuring and allowing for thermal effects. After such efforts have been made the antenna must, under the precision operating conditions (see 2(d) above) suffer no nonrepeatable pointing errors of this type which exceed 7 arc seconds in magnitude.

(iii) 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 axis and 80°/minute above the azimuth axis in winds to 45 miles/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.

In the slewing mode the antenna shall be capable of accelerations of $0.25°/\text{second}^2$ about both axes.

(iv) 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 cone of avoidance near the zenith when in the tracking mode shall have a half-angle less than 2.5°.

3. General Requirements

(a) Feed legs and apex. The feed leg supports shall be designed to support either a subreflector of 2.5 m diameter, weighing approximately 800 lbs, or a prime focus feed of approximately the same weight. The feed legs shall also be designed to support a cable weight of 8 lbs/foot on each leg. The apex structure shall be so designed that a clearance of 18 to 24 in. (with 18 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. The feed legs and apex structure, including a 2.5 m subreflector, shall not cause RF blockage in excess of 6 percent of the total aperture area.

(b) Vertex equipment room and feed mounts. An approximately circular room of 78 sq. ft area, having an inside diameter of approximatley 10 ft 0 in. by 7 ft 6 in. height for mounting of feeds and equipment shall be provided by the antenna manufacturer. The floor of this room shall be parallel to the ground with the antenna pointed at zenith and shall be a minimum of 8 ft 0 in. below the vertex of the antenna. This room shall be provided with the following features:

Mounting provisions for up to five 2 ft x 2 ft x 7 ft floor mounted racks with a total weight of 2000 lbs.

An access door or hatch for access by personnel and for means of installing racks by use of hoist.

Thermal insulation and air conditioning to provide 23° C $\pm$ 1° C (74° F $\pm$ 2° F) temperature control with an interior heat input of up to 3 kW. No specific humidity conditions are required.

The roof of the building shall contain a removable mounting ring for the mounting of feeds. Dimensions of this ring shall be determined in the design stage, but it is anticipated that it will be approximately 8 ft 0 in. in diameter.

4. Conclusion

There are many further details in the VLA specification dealing with foundations, the waveguide run, power supplies, brakes, limit switches, etc., which do not seem needed yet in this document.