THE VLB ARRAY +

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ABSTRACT

The VLB Array (VLBA) is a synthesis radio telescope which has been designed to extend the resolution of the VLA in order to allow sub-milliarcsec studies of compact galactic and extragalactic radio sources over a wide range of wavelengths and spectral resolution.

I. BACKGROUND

Shortly after the first observations made with independent oscillator-tape recording interferometers (Very Long Baseline Interferometer or VLBI) (Broten et al. 1967; Bare et al. 1967), it was realized that VLBI was a powerful tool which could be used to study a wide variety of problems in galactic and extragalactic astronomy, including fundamental astrometry, terrestrial geodesy and geophysics, as well as in fundamental physics (e.g. Gold, 1967; Shapiro, 1967; Cohen et al. 1968; Burke 1969).

It soon became apparent that a multi-element radio telescope array with dimensions comparable to the size of the Earth would be needed to study the complex structure found in compact radio sources (e.g. Swenson and Kellermann 1975), and in 1974 the NRAO began to investigate the feasibility of constructing a dedicated VLB Array to complement and extend the Very Large Array (VLA) then being built on the Plains of San Augustin in New Mexico. By 1977 it was clear that the technology developed for the VLA and being used for VLBI experiments around the world was sufficient to construct a radio array of truly global dimensions, and the specifications and conceptual design for such an array was circulated as an NRAO report, An Intercontinental Radio Telescope (ed. K. Kellermann). In 1978 a Canadian group reported on a similar array planned for Canada (ed. T. Legg). The concept of a dedicated VLB Array was further developed in the U.S.A. at Caltech and at NRAO, and two further reports were issued, in 1980 A Transcontinental Radio Telescope (Caltech, ed. M. Cohen), and in 1981 Design Study for the Very Long Baseline Array (NRAO, ed. K.

R. Fanti et al. (eds.), VLBI and Compact Radio Sources, 377–382.

Kellermann), which further specified the system design and set performance specifications. Likewise, several updates to the Canadian concept were made during the period 1978 to 1983.

In 1982 following a three-year study, the Astronomy Survey Committee ("Field Committee") of the U.S. National Academy of Science recommended the construction of a Very Long Baseline Array Radio telescope as the highest priority for major new ground-based astronomical facilities, and in May 1982, the NRAO submitted to the National Science Foundation a proposal for the design, construction, and operation of the VLBA.

This proposal, which was based on the earlier design studies, was the result of a ten-year effort in which more than 60 scientists and engineers throughout the country had contributed. Detailed engineering design and prototyping of individual subsystems will continue through 1984, and construction of the VLBA is expected to start in 1985. Partial operation is scheduled to begin in 1987 when the first antennas are completed, and full operation is expected by the end of 1988.

II. PERFORMANCE SPECIFICATION AND SYSTEM DESIGN

The number and location of the VLB Array elements has been chosen to give the best possible resolution and image quality consistent with budgetary constraints. To simplify the operation and management of the Array, it has been decided to place all elements on U.S. territory. The Array will contain 10 antenna elements spaced throughout the United States from Hawaii to Puerto Rico. Two of these will be in the state of New Mexico, close to the VLA; the others being in Massachusetts, Iowa, Washington, California, Arizona, and Texas. The two New Mexico antennas will be located in such a way that the baselines between these antennas and the VLA will to some extent fill in the spacings intermediate between the VLA and VLB Array. It is hoped that in the future three more antennas may be added in this area to give essentially continual coverage between the compact VLA "D configuration" and the full 8000 km VLBA dimensions.

The local oscillators at all stations will be synchronized by hydrogen maser frequency standards, and the IF signal will be recorded on magnetic tape for later playback in a central processing facility. One of the New Mexico antennas will be about 70 km south of the center of the VLA and will be connected to the VLA Control Center via a microwave data link. At all times this antenna will be remotely operated with the local oscillator reference and tape recorder located at the VLA Control Center. For some applications it will be used as a real time coherent extension of the VLA, effectively doubling the resolution of the VLA at the cost of degraded dynamic range. On the other hand, for VLBA problems requiring a relatively large field of view, one VLA antenna (or in some cases all three outer antennas of the A configuration) can be used together with the 10 VLBA elements;

and for special cases all 27 VLA antennas can be used together with the VLB Array to obtain very high sensitivity. All of the elements will be controlled and monitored in real time by a single array operator via leased telephone lines, and each antenna will normally be unattended except for changing magnetic tapes.

The basic system specifications for the Array are outlined in Table I. The wide geographic coverage of the array and maximum operating wavelength gives the best possible resolution which can be obtained from the surface of the Earth consistent with current antenna and receiver technology as well as consideration of a reliable and cost effective operation. The number of antenna elements allows about 80 percent of the amplitude and phase information to be obtained from self-calibration procedures and is sufficient to give good image quality (dynamic range) over a wide range of declination.

TABLE I

DESIGN SPECIFICATIONS

Number of Elements	10
Size of Elements	25m
Overall Size	8000 km
Wavelength Coverage (10 bands)	0.7 cm to 90 cm
Resolution	0.2 to 24 milliarc sec
Sensitivity	0.1 milli Jy
Polarization	Linear and circular
Spectral Resolution	0.2 Hz to 50 kHz

Antenna Elements. 25-meter diameter antennas were chosen, as antennas of this size with the desired accuracy can be readily fabricated with conventional techniques, and gives a good compromise between collecting area and shortest operating wavelength. Each element will be a conventional wheel and track structure designed for reliable low maintenance operation and will have a shaped paraboloid primary surface to give a high efficiency. It is hoped to build a reflector surface with an rms surface accuracy $\lesssim$ 0.45 mm to allow operation at frequencies $\gtrsim$ 40 GHz. At frequencies above 1 GHz, operation will be from the Cassegrain focus, and an asymmetric secondary reflector will be rotated to illuminate the eight feed horns located at the Cassegrain focus. Prime focus feeds will probably be used at the two lowest frequencies. Dual frequency operation can be provided with dichroic reflectors and is initially planned for the S/X wavelength bands commonly used for the NASA and NGS geodetic programs.

Radiometer Systems. Receivers for the two lowest frequencies will use relatively simple feed systems and ambient temperature GASFET amplifiers. In the six intermediate wavelength bands, GASFET amplifiers cooled to 20K will be used to give the best possible sensitivity consistent with reliable operation and economic construction, while MASER amplifiers are being considered for the two shortest wavelengths to give state-of-the-art sensitivity. Rapid change of the observing wavelength will be possible from the Operations Center, allowing flexibility in observing programs as well as minimizing the impact of receiver failures or poor weather conditions.

The sensitivity and resolution in each of the 10 planned wavelength bands is shown in Table II. The values given for noise fluctuations represent the noise in each picture element provided that there is a reference feature typically ten times stronger visible on all baselines which is sufficiently strong to phase the array in a typical coherence time of 10 minutes. Such reference features are most conveniently used if they are within the primary beam of the antenna pattern; but phase referencing to nearby sources can also be used. Water vapor radiometers will be installed at each element to measure the water vapor content in the atmosphere in order to minimize the phase variations due to fluctuations in atmospheric water vapor along the line of sight. Use of the full VLA will also allow self calibration of the VLBA on sources weaker by a factor of five than indicated above.

TABLE II

VLB ARRAY
SENSITIVITY AND RESOLUTION

FREQ. (GHz)	RCVR	SYSTEM TEMP-K	RMS NOISE 8 Hours-mJy	RESOLUTION MAS
0.32	FET	65	0.16	24
0.61	FET	55	0.1	13
1.4/1.7	FET	29	0.035	5
2.3	FET	31	0.035	3.5
5	FET	37	0.04	1.6
8.4	FET	40	0.05	0.9
10.7	FET	45	0.05	0.7
15	FET	65	0.06	0.5
22	MASER	45	0.06	0.35
43	MASER	75	0.16	0.2

I.F. and Recording System. The I.F. system is being designed to accommodate up to 32 frequency channels each with a bandwidth selectable between 125 kHz and 16 MHz. The recording system will operate in a 2-bit or 4-bit mode at a normal rate of 100 Mbps (50 MHz bandwidth), and for limited periods at rates up to 200 Mbps (100 MHz bandwidth) or more for high sensitivity continuum observations, or at lower rates as appropriate for narrow band spectral line observations. The system is expected to be transparent to the specific recording medium, to allow for improvement in this rapidly developing area with a minimum of system retrofits, and to keep, where appropriate, compatibility with older VLBI recording systems which are in present use.

Initially, the record/playback system will be based on inexpensive consumer type Video Cassette Recorders. Each recorder will be modified to write at a 12.5 (or 25) Mbs data rate, and a bank of 8 (or 4) recorders will be used to obtain the full 50 MHz (100 Mps) bandwidth. A second recorder rack will normally be available as a spare at each station, but for limited periods can be used to double the recorded bandwidth, at the expense of increased tape consumption. Unattended operation of each station for at least 24 hours between tape changes is planned.

Processor System. The correlator system will be able to handle the input from up to 19 antenna elements in the normal continuum mode, and 14 antennas with full polarization processing. In the spectroscopic mode, up to 512 frequency channels will be available with a frequency resolution down to 62 Hz.

III. FUTURE EXPANSION

Like all arrays, the VLBA can be expanded to improve the sensitivity, resolution and dynamic range. The addition of a single element in South America would greatly improve the resolution in the north-south direction, while extensions to the Pacific will also be of interest to supplement and extend the new Australia Telescope, as well as the new mm dish in Japan and the dedicated VLBI dishes planned in China. The future placement of a large antenna in Earth orbit will even further extend the power of the VLBA (e.g. Burke, this volume).

On more immediate time scales, the use of other large radio telescopes such as the VLA, Arecibo, and Bonn 100-m will be used together with the VLBA, as will the new VLBI antennas being constructed in Italy and planned in Canada. This will increase both the angular resolution and image quality, as well as greatly enhance the sensitivity. Of particular interest will be the intermediate scale high sensitivity baselines available from European antennas.

IV. OPERATION

Normally each antenna element of the VLB Array will run entirely under control from an Operations Center. A few technician/operators will be available at each site, however, for inspection, routine maintenance, and the simpler unscheduled repairs of malfunctioning equipment. The local staff will also be responsible for updating operating systems at the local control computer, for changing and shipping the data tapes to the Operations Center, for security and precautionary oversight, for emergency intervention and for routine start-up and shutdown procedures.

The Operations Center will provide for major maintenance and repair requiring personnel with special skills, special equipment, or major replacement parts. However, since it is planned to replace complete modules in the case of failure, many such replacements can be easily performed by the local site personnel. Defective modules will be returned to the Operations Center for repair. This procedure, while requiring a somewhat larger than normal inventory of spare parts, will reduce travel and personnel costs, and keep Array downtime to a minimum.

The Array will be operated using a preplanned program under the control of a central computer, which will simultaneously monitor the performance of the antennas and receivers as well as the meteorological conditions at each site. An Array Control Operator will be present at all times at the Operations Center to intervene when necessary and to carry out various housekeeping tasks. From time to time, brief samples of the received signal at each antenna will be sent to the Operations Center via the telephone lines and correlated in nearly real time to check that all components of the Array are functioning properly and to monitor meteorological effects on the data.

Many individuals from the U.S. university community as well as at NRAO are actively involved in the design of the VLB Array, and in particular the radio astronomy laboratories at Caltech and MIT are working with NRAO in all phases of the design and construction. When completed, the VLB Array will be operated by the National Radio Astronomy Observatory as a national facility available to all qualified scientists. As with other NRAO facilities, observing time will be based on scientific merit without regard to institutional or national affiliation. The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

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