THE VLB ARRAY: A NEW GEOPHYSICAL TOOL

Edward B. Fomalont
National Radio Astronomy Observatory
Charlottesville, VA 22903-2475

The National Radio Astronomy Observatory is constructing a Very Long Baseline Array (VLBA) consisting of ten antennas across the USA, between Hawaii and the Virgin Islands. The array will be a dedicated instrument for producing milliarcsecond images of radio sources. However, exciting geophysical applications of the array are obvious and, furthermore, detailed geodetic, astrometric and environmental parameters are necessary for the VLBA to achieve its full sensitivity, resolution and positional capabilities.

Three aspects of the VLBA and its possible relationship with the geodetic community will be discussed. First, the array specification, system design and construction schedule will be briefly described. Not all of the decisions concerning the VLBA are final; there may be some modification to the ultimate instrument. Secondly, some of the more obvious astrophysical and geophysical applications of the VLBA will be summarized. Finally, the questions and problems of how the VLBA and the geodetic community can benefit maximally from this powerful array, will be touched.

THE VERY LONG BASELINE ARRAY: A Short Description

A good description of the VLBA can be found in Science (Kellermann and Thompson 1985). More technical details on the design and construction can be obtained in VLBA memos available from NRAO.

The VLBA consists of ten 25-m diameter antennas between Hawaii and the Virgin Islands. The configuration of the antennas, shown in Figure 1, has been optimized for best resolution from within the USA to synthesize a relatively uniform aperture with at least 6 hours of observations at declinations north of -20 degrees. Proximity to the VLA and the use of high, dry western US sites and other existing facilities were also a consideration. The baselines range in separation from 200 km to 8000 km with a fringe spacing between 1.5 and 60 milliarcsec at 5.0 GHz.

A. K. Babcock and G. A. Wilkins (eds.), The Earth's Rotation and Reference Frames for Geodesy and Geodynamics, 445–451.

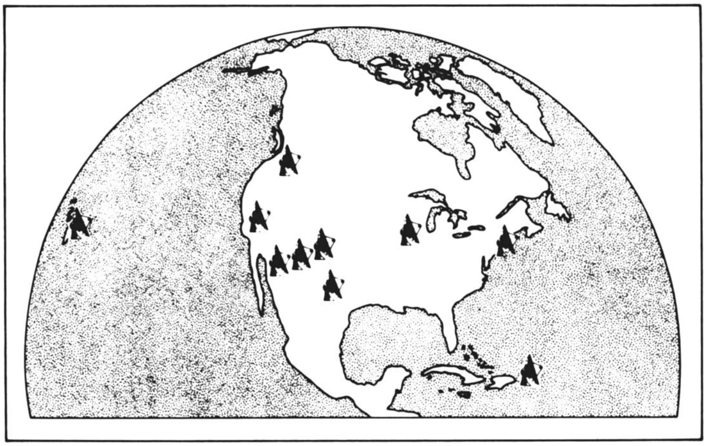

Figure 1. The VLBA configuration. The location of the ten antennas which are not drawn to scale.

Each VLBA antenna will be equipped with radio receiving systems between 330 MHz to 43 GHz in 10 frequency bands which are listed in Table 1. The feed-subreflector design will be similar to the VLA and permit rapid change among the frequencies. At each band there will be four independent receivers; two orthogonal polarizations at two independent frequency settings, each with a maximum bandwidth of 128 MHz and each tunable within a 500-MHz range at most bands. Eight frequency converters in the intermediate frequency system will produce 8 frequency channels (16 frequencies for both upper and lower sidebands) which can be used for bandwidth synthesis. Dual S/X band frequency pairs are planned; several other frequency pairs are being considered. The recording system will be similar to the MKIII system, developed at MIT's Haystack Observatory, largely under NASA sponsorship. Thus, there will be reasonable compatibility with the existing VLBI geodetic network and there will be no severe limitations in using VLBA antennas within that network.

The VLBA correlator is still under design consideration. It is likely that it will be an "FX" type (Chikada et al., 1984) where the IF signals are Fourier-transformed before correlation. The correlator will support 20 antennas with 1024 spectral points. The correlator output will be archived and also transported to the off-line computing system where fringe-fitting, self-calibration and image formation will be carried out under the AIPS system. Astrometric and geodetic software systems will be available.

Normally, each antenna element will run entirely under control from the operations center in Socorro, NM. A few technician/ operators will be on location at each site for routine maintenance and tape changing. A complete set of modules will be available in case of most "routine" failures. The VLBA will be operated under a

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preplanned program under control of the central computer which will monitor the antenna and receiver performance.

TABLE 1. VLBA RECEIVERS

Band Designation *1*			Frequency Range [GHz]	Focus *2*	Feed Type *3*	Aper Effc *4*	Ampl Type	Optg Temp [K]	Rcvr Temp [K]	System Temp [K]
0.33	P		0.312→0.342	P	D	0.50	FET	320	30	104
0.61			0.580→0.640	P	D	0.49	FET	320	32	66
1.5	L		1.35→ 1.75	C	CH	0.57	FET	15	12	30
2.3	S		2.15→ 2.35	C	H	0.71	FET	15	16	36
4.8	C		4.6 → 5.1	C	H	0.72	FET	15	20	35
8.4	X		8.0 → 8.8	C	H	0.71	FET	15	27	48
10.7		*5*	10.2 →11.2	C	H	0.71	FET	15	29	45
15.	U		14.4 →15.4	C	H	0.69	FET	15	45	63
23.	K		21.7 →24.1	C	H	0.66	HEMT	15	40	67
43.	Q		42.3 →43.5	C	H	0.51	SIS	3.5	40	75
89.	W	*5*	86? → 92?	C	H	0.18	?	?3.5	?	?

Notes: *1* GHz frequency, to 2(+) significant figures;
Conventional radio (and VLA) letter codes.
2 P => Prime focus, C => Cassegrain focus.
3 D => Crossed dipoles, CH => Compact corrugated horn,
H => Conventional corrugated horn.
4 Total aperture efficiency, including all known effects.
5 Optional receivers, not included in basic Array budget.
(one 10.7-GHz receiver part of initial complement at PT.)

Dual-Frequency Pairs --
Planned: S/X bands.
Options: C/U, C/K, U/Q, U/W

The construction and pre-completion operations depend on the year-to-year funding which is harzardous to guess. The first antenna at Pie Town, NM is now under construction and should be ready for observations at the end of 1987. It will have nearly a full complement of electronics and will be used in the VLBI and geodetic networks to debug the system and to develop useful software. Four telescopes will be in operation by the end of 1988, and one telescope per year will then be added to the array. The correlator will be constructed, and possibly put into operation with a limited number of stations by 1990, when six VLBA antennas will be on-line. The entire project will not be completed until about 1994, assuming a funding level of $9M per year.

USE OF THE VLBA

The astronomical goal of the VLBA is the production of high quality milliarcsecond images of radio emission from celestial objects. The attainment of this goal requires the phasing of the signals between the antennas to a small part of a wavelength, typically a few millimeters! The achievement of this accuracy over long periods of time, i.e., real coherence, may never be routine, but it is a goal of the instrument: it can only be obtained with full geodetic information since the VLBA is on a moving, distorting, platform; and detailed knowledge of the environmental conditions which affect the propagation of the radio signals will be required.

This strong coupling of the astrophysical use of the VLBA to its geodetic use is not fully realized because nearly all VLBI observations have been limited to strong sources which produce high signal-to-noise ratio over a few minutes during which the array is phase stable. The phasing over longer periods of time is then accomplished by a self-calibration technique (e.g., Readhead and Wilkinson, 1978) which determines the antenna phase and gain behavior needed to produce an image of good quality--by which we mean an image which seems to be in focus and also conform to some preconceived notion of what it should look like. Use of the technique has produced exciting results, (e.g., the discovery of superluminal radio sources), but it will be a severe handicap for the VLBA if quality images can be made only for strong sources.

The VLBA will, of course, be an exciting astrometric instrument with the capability of milliarcsecond and in some cases, tens of microarcsecond accuracy. However, accuracy will be severely limited without precise geodetic, tropospheric and ionosphere information during the observations. Some examples are:

1. Tests of General Relativity: Radio bending experiments using quasars and space probes. Variations of the gravitational constant G.

2. Establishment of an optical-radio coordinate grid tied to the quasars with milliarcsecond accuracy. More accurate ephemerides. Use of stars with maser emission lines. Pulsar timing positions and solar system ephemerides.

3. Measurement of parallaxes with milliarcsecond accuracy.

4. Measurement of proper motions with tens of microarcsecond accuracy.

5. Statistical distances for objects by comparing radial and transverse motions.

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The specific geodetic uses of the VLBA have been described in the proceedings of the workshop "Multidisciplinary Use of the Very Long Baseline Array" (1983). Several antennas are at interesting geological locations; Owens Valley, Hawaii and the Virgin Islands and a continuous monitor of their separations will be obtained. Polar motion, earth rotation, precession and nutation constants will be obtained using VLBA calibration data and more specific programs.

That the VLBA will be an unchanging instrument of great stability will be extremely important in the determination of long term astrometric/geodetic variations. The VLBA will be scheduled as a dedicated instrument for any scientific project of merit so that many short time scale phenomena can be detected and monitored as necessary.

INTERACTION OF THE VLBA AND THE GEODETIC COMMUNITY

The types of observations and calibrations at the VLBA can only be guessed at the present. Every week or two we expect to observe calibrators over the sky for about 12 to 24 hours to determine the separation of the antennas, UT1, the direction of the pole and other instrumental parameters. Perhaps once a day there will be about 30 minutes to one hour of similar observations to determine changes in the VLBA parameters since the previous calibration session. Whether these determinations are more accurate than those which will be available from the geodetic community and/or more quickly available is unclear. Most imaging observations will probably use alternating observations of the radio source and a nearby calibrator as a phase reference. With good a priori parameters and accurate water vapor determinations we hope to keep the VLBA in phase coherence, at least at the lower frequencies, in good weather. Frequency rapid changeability will permit switching of programs as weather conditions change.

All information associated with the calibration runs will be available for long term analysis. For example, the VLBA will determine a catalog of radio sources and monitor their changes at a variety of frequencies. Station vectors, polar motion, UT1 will be routinely determined and compared with external evaluations. Simultaneous scheduling of calibration runs by the VLBA and other arrays might be useful. The astrometric/geodetic software used by the VLBA should be similar with that used by the geodetic community. All VLBA data, especially those associated with calibrator observations, should be conveniently archived so that it can be easily transported and utilized by outside groups. Such a format might be similar to that of the "B" tapes generated by Haystack Observatory for the Crustal Dynamics Project. Special instrumentation and reduction methods for lessening the effects of tropospheric and ionospheric propagation errors should be coordinated between the communities.

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Joint observations of the VLBA with other geodetic and astronomical groups will be possible. There are no compatibility problems between the VLBA and other geodetic telescopes. The recorder design is like that of the current Mark III system, the IF system will support 8 independent frequencies (perhaps expandable to 16) and dual S-X/band frequency systems will be implemented. After completion of the first VLBA antenna at the end of 1987, it will become an active part of the VLBI network and also participate in geodetic experiments. This will help NRAO debug the VLBA electronic system and tend to guide the software into a more compatible system with the other arrays. Also, the use of more than ten antennas will produce better images of radio sources, more accurate astrometric/geodetic information and tie the VLBA system into that of other arrays. The planned correlator will be able to handle up to twenty antennas simultaneously by 1994.

The VLBA will spend about 10% to 20% of the observing time on calibrations, which is standard practice for the VLA at the present time, in order to determine earth rotation, polar motion, precession and nutation parameters with high accuracy. Proposals for longer periods of observing time on specific geophysical questions (details of earth tides, slight variations in rotation rates caused by large storms, etc.), should go through the same refereeing system as the astronomical proposals with the most important scientific projects getting the observing time.

SUMMARY

There is strong feeling that the VLBA will be an effective tool to determine geophysical parameters which will significantly improve the imaging capabilities of the instrument.

Instrumental compatibility of the VLBA with other VLBI arrays and geodetic arrays is good.

There will be extended use of the first VLBA antenna at Pie Town, NM with the VLBI network and the crustal dynamics project. These observations will help debug the VLBA antennas and help generate more compatible software systems.

The VLBA calibrator data base must be carefully archived for internal and external use. This data base will prove invaluable for many long term astrometric and geodetic problems.

Combination of the VLBA with other antennas will produce a powerful imaging instrument and geodetic tool. The correlator is being designed to handle up to 20 antennas simultaneously.

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A concerted effort is needed to minimize the effects of the troposphere and ionosphere. Better water vapor radiometers must be designed and understood. The VLBA will have dual frequency capability to determine the ionospheric refraction and to determine the tropospheric phase fluctuations at high frequency by scaling the fluctuations at lower frequency.

REFERENCES

Chikada, Y., et al., 1984, Indirect Imaging, edited by J. A. Roberts, Cambridge University Press, p. 387.

Kellermann, K. I. and Thompson, A. R., 1985, Science, 229, 123.

Multidisciplinary Used of the Very Long Baseline Array, 1983, National Academy Press.

Readhead, A.C.S. and Wilkinson, P. N., 1978, Ap. J., 223, 25.

DISCUSSION

Johnston: How soon will the VLBA recorders be available? Will they be compatible with the present Mark III recorders used for geodesy?

Reply by Whitney: VLBA terminals will have capability of writing tapes in Mark III format. It is not yet clear whether the VLBA correlator will be able to accept Mark III format tapes. Interested parties should contact NRAO regarding availability of VLBA data-acquisition systems for non-VLBA sites.

Reply by Clark: Compatibility between VLBA and Mark III-A is quite high. The recorders are identical, although operating modes are different. The VLBA specifications call for longer recording times. But this is due to the use of thinner tape on slightly larger tape reels. The major difference is that planned initial implementation of VLBA calls for 8 vs. the Mark III's 14 discrete frequencies.

Herring: Can the 8 video converters be easily 14 video converters?

Reply by Fomalont: Yes, it will be possible to double the number of converters to 16.

Nothnagel: When will outside customers be able to acquire a VLBA recording terminal from the NRAO or Haystack production line? Do they have to wait for all 10 VLBA terminals to be completed?

Reply by Fomalont: At this time it is difficult to determine the rate of production of VLBA terminals.