VERY LONG BASELINE INTERFEROMETRY (VLBI) EARTH PHYSICS*

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HISTORICAL ORIGINS OF VLBI

Historically, applications of interferometry have been primarily for astronomical purposes beginning with the work of A.A. Michelson and F.G. Pease in 1920. These early experiments used optical wavelengths to measure the angular diameters of stars. The method operated by combining starlight received from two separate optical paths, which had to be established and maintained at equal optical lengths (Figure 1). This task proved to be extremely difficult and prevented the primary mirrors from being separable by more than 20 ft., mainly because of atmospheric dissimilarities in the two interferometer arms. A dissimilarity in optical path of only 0.2μ (1/2 an optical wavelength) is sufficient to de-

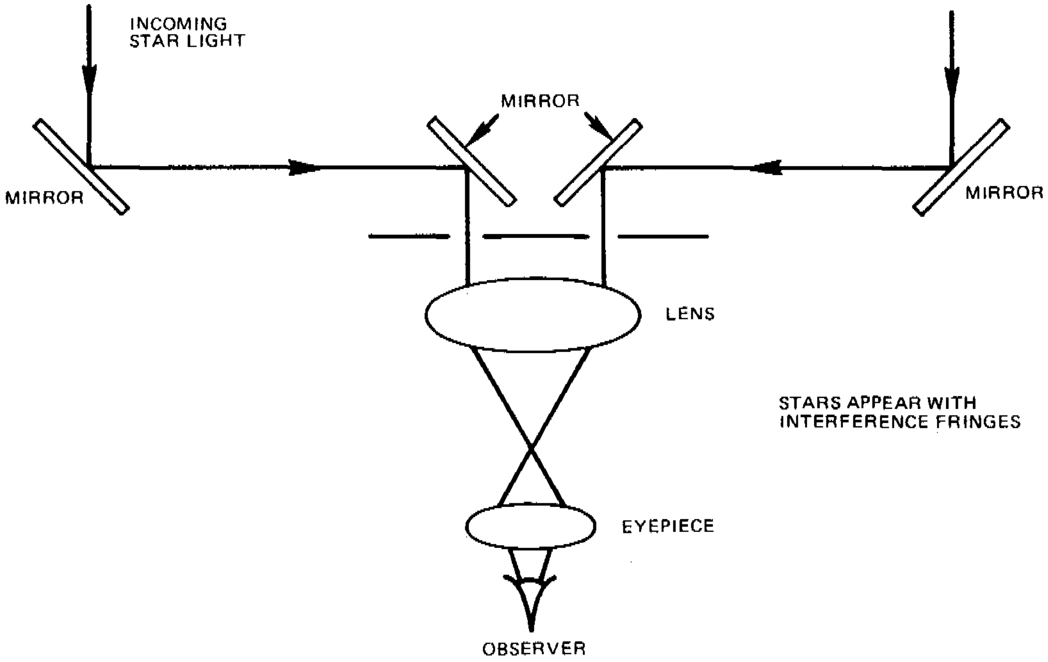

Figure 1. Michelson/Pease stellar interferometer.

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stroy the interference pattern (or fringes) which is the output of any interferometer system.

With the emergence of radio astronomy as a discipline in the 1930s came the desire to create the analog of the Michelson/Pease stellar interferometer using radio waves instead of optical wavelengths. These early radio interferometers were the so-called hard-wired systems, because cables or some other phase-stable communications link was needed to derive the first local oscillator signals (Figure 2). As with its optical forerunner, the radio paths had to be stable to better than one-half an RF wavelength to maintain the fringe output of the interferometer. The practicality of laying cables has limited short baseline interferometers to about 1 km, whereas microwave relay links have allowed antenna separations up to about 100 km.

Because the resolving power of an interferometer is dependent on the ratio of the wavelength to the antenna separation, there was the inevitable desire to move the antenna spacing to intercontinental distances, if possible. The breakthrough in achieving these very long baselines occurred in 1967[1,2] because of improvements in quantum electronic frequency systems which afforded essentially identical performance of two or more separate devices for generating local oscillator signals. The improved frequency systems eliminated the need for a phase-stable link between the two receiving stations, making it possible for the stations to be separated by arbitrarily large distances limited only by the earth's diameter. This, then, was the origin of the radio astronomy technique of very long baseline interferometry (VLBI).

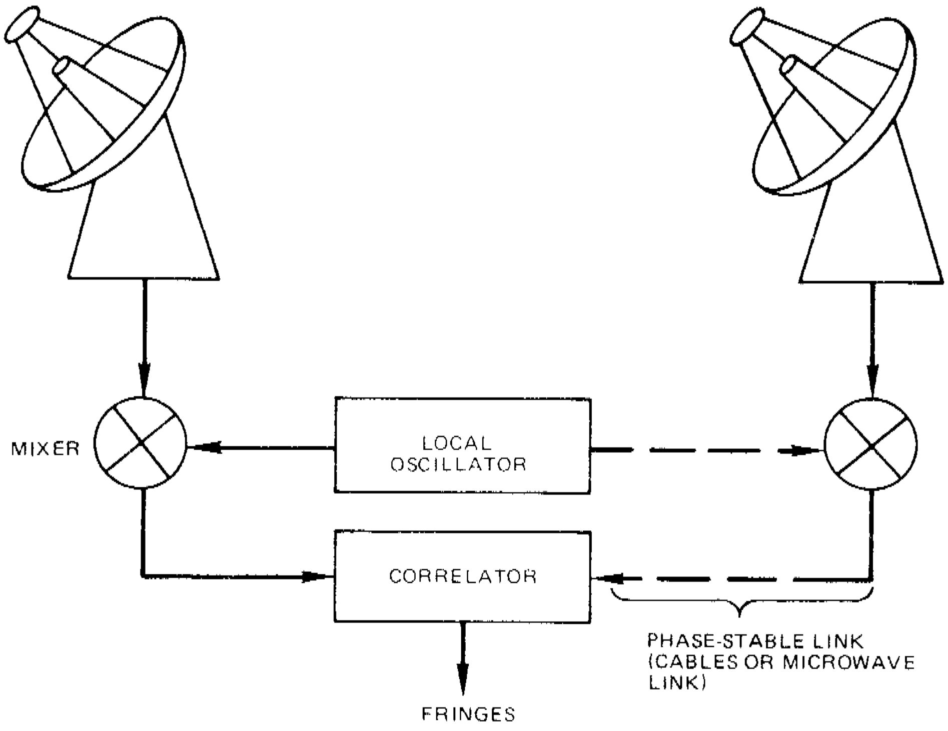

Figure 2. Conventional hard-wired radio interferometer.

Perhaps it would have been more apt to term the method independent station radio interferometry, so as not to imply that only very long baselines were allowed.

When the baselines are comparatively short, and phase-stable communication links are available, the outputs of the heterodyne receivers are conveniently combined at a common site to produce fringes. However, on a very long baseline the output of the receivers must be handled differently. The only method so far demonstrated consists of recording receiver output on magnetic tapes along with time codes from each station. Two implementations exist in this type of recording: an analog approach favored by the Canadians and a digital method used by virtually all U.S. teams. These magnetic tapes are brought together for cross-correlation processing, usually several days or weeks after the time they were recorded. It is the cross-correlation process which yields the fringe response of the interferometer. A schematic diagram of the VLBI technique is given in Figure 3.

Since the original experiments in 1920, interferometry has been used for astronomical applications and particularly for measuring the angular diameters of the sources of light or of radio waves. The early publications on VLBI, however, correctly identified applications to geophysics,[3,4] although the predictions of centimeter-level measurements are yet to be realized over very long baselines.

For those interested in the general VLBI literature and the use of this concept in the study of spatial structure of celestial radio sources, general survey articles[5,6] will be of interest.

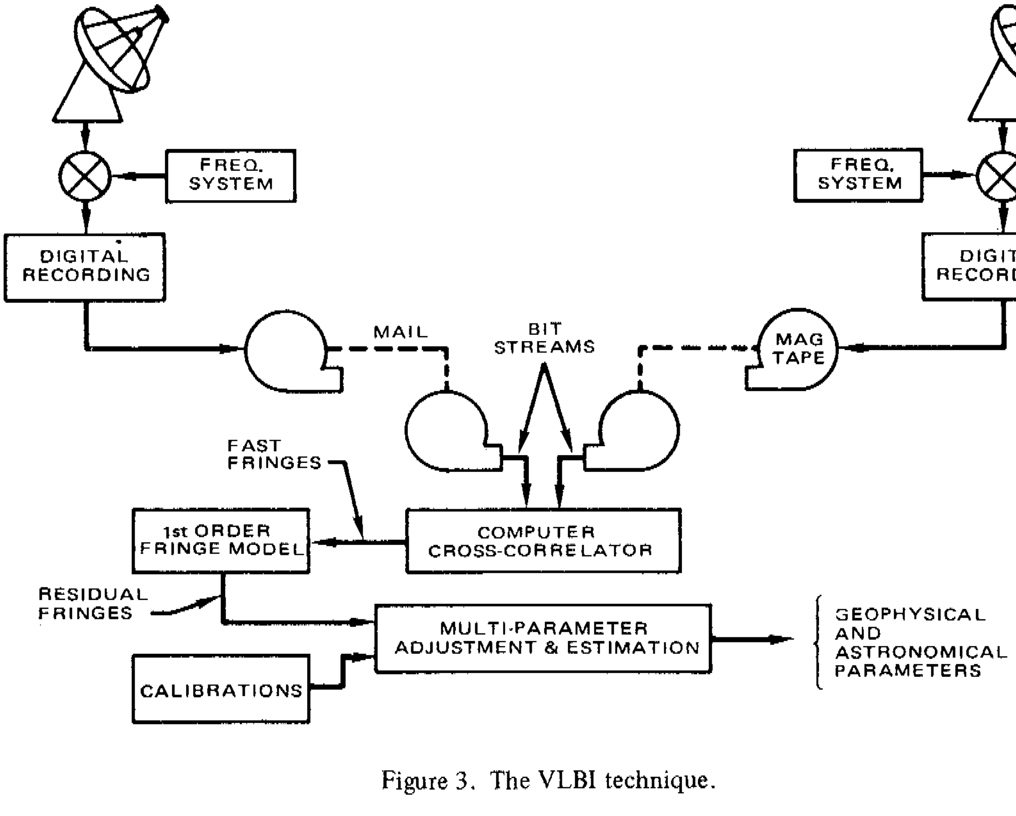

Figure 3. The VLBI technique.

THE VLBI TECHNIQUE

In VLBI measurements, the radio signal produced by a distant source is recorded simultaneously at two radio antennas. Because of a difference in ray paths, reception of the signal may be delayed in time at one antenna relative to the other. By cross correlating the two signals, the time delay and/or its time derivative may be determined.[7,8] When narrowband recording equipment is used, only the derivative of the time delay may be measured with adequate precision. If the radio signal is generated by an extragalactic object, the radio source may be regarded as a fixed object because of its great distance.

The time variation of the time delay is due entirely to the earth's motion, but depends, of course, on the source location and the baseline vector between the two antennas. In general, measurement of the derivative of the time delay for many natural sources can lead, by means of a least-squares analysis, to the determination of source locations; the baseline vector; and earth-motion parameters, such at UT-1 and polar motion.

Figure 4 shows a schematic diagram of a radio interferometer station pair, while Figure 5 gives the geometry of the situation. As these two antennas are separated by a distance $|\vec{D}|$, there may be a difference in the time of reception of the signal at the two antennas. This delay, τ_g, is given by

$$\tau_g = \frac{D}{c} \cdot \hat{s} \tag{1}$$

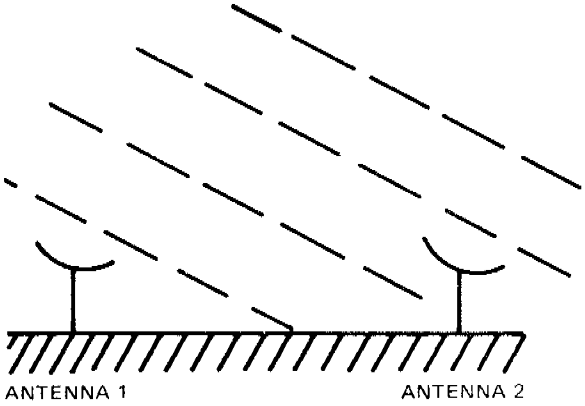

Figure 4. Interferometer pair.

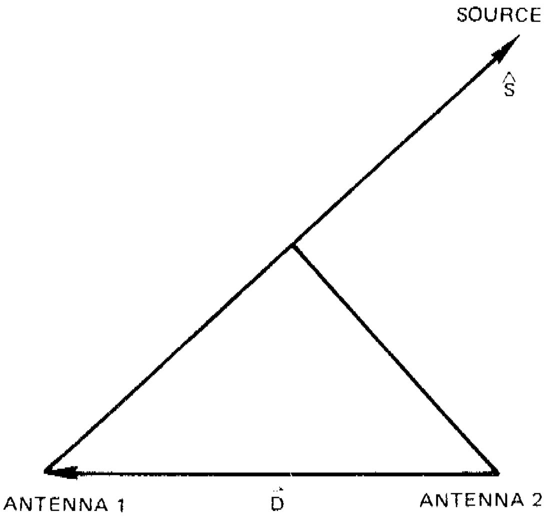

Figure 5. Interferometer geometry.

- 10 cm MEASUREMENT ACCURACY IN A SINGLE DAY
- INHERENT ACCURACY INDEPENDENT OF BASELINE LENGTH
- REFERENCE EARTH LOCATIONS MEASURED IN THREE DIMENSIONAL GEOCENTRIC COORDINATES RELATIVE TO EXTRAGALACTIC RADIO SOURCES
- OPERATES IN VIRTUALLY ALL WEATHER
- NO TRANSMISSION OF LIGHT OR RADIO SIGNALS NECESSARY (NON-ELECTROMAGNETICALLY POLLUTING)
- INHERENTLY PASSIVE, USING ONLY NATURAL RADIO SIGNALS (NO CYCLOMATES)

Figure 10. ARIES system characteristics.

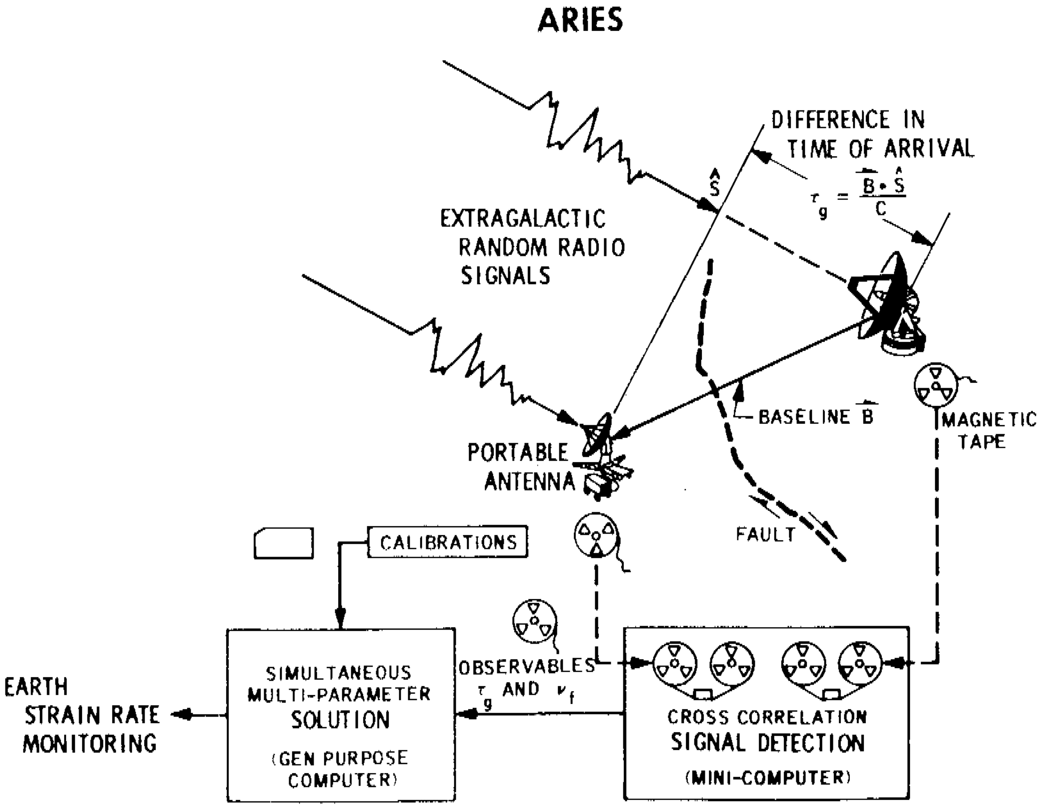

Figure 11. Schematic of ARIES implementation.

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