The Parkes-Tidbinbilla Interferometer

R. P. Norris, Michael J. Batty, M. J. Kesteven, and K. J. Wellington, Division of Radiophysics, CSIRO, Sydney

Abstract: We report the development of a radio-linked interferometer which uses the 64-m telescope at Parkes, NSW, and one of the NASA antennas (64-m or 34-m) at Tidbinbilla, ACT. With a baseline of approximately 275 km, this is the world’s longest real-time interferometer; it will be usable at frequencies of 1.6, 2.3, 8.4, and 22 GHz to give angular resolutions of 0.13, 0.09, 0.03, and 0.01 arcsec respectively. The interferometer has already operated successfully in a limited mode and is expected to become fully operational in its initial configuration by September 1985. Operation at a range of frequencies and with progressive enhancements is planned up to the commissioning of the Australia Telescope in 1988.

Introduction

The Australia Telescope, due for completion in 1988, will comprise a 6-km compact array (CA) in northern NSW and a long baseline array (LBA). The latter includes the tied compact array, the 64-m Parkes antenna, and a new 22-m antenna to be located at Siding Spring. The LBA will also make use of the NASA antennas at Tidbinbilla and the University of Tasmania’s 26-m antenna to be located near Hobart. The interferometer described here uses two of these antennas (Parkes and Tidbinbilla) to form a single baseline interferometer with a length of 275 km. It was conceived primarily as a prelude to the Australia Telescope, and as such will be useful both as a test-bed on which to tackle some of the problems that we will encounter on the AT, and also as a first step towards the establishment of frame-of-reference sources for the AT. In addition it constitutes a powerful instrument with which to tackle some current astronomical problems.

The interferometer is at present limited to a bandwidth of 0.5 MHz and, because of the use of a rubidium standard at Parkes, to a coherence time of 10 min. We call this mode of operation ‘Phase 1’, since it is hoped to increase the bandwidth to at least 5 MHz in Phase 2 operation. Additional upgrades, which may take place at the same time, will include phase stabilization.

The overall performance is shown in Table 1. Despite the restricted bandwidth of the Phase 1 interferometer, the use of large telescopes produces a highly sensitive instrument. Furthermore, the coherence time at 1.6 and 2.3 GHz is sufficient to allow switching between sources within one coherence period, thus permitting astrometric observations.

Technical Details

A novel feature of this instrument is that many of the interferometer functions which have traditionally been

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*Except where shown otherwise, these figures are for the Phase 1 interferometer operating at 2.3 GHz, and assume the use of the 64-m antenna at Tidbinbilla, with a 20 K noise temperature. Use of a 34-m antenna at Tidbinbilla degrades the sensitivity by a factor of about two, but leaves other parameters unchanged.
implemented in hardware are instead software-based. As a result this interferometer has been built at low cost and with very little specially constructed hardware. It differs from previous instruments in that, by measuring a full cross-correlation function over 512 delay channels, most of the phase and delay corrections may be performed by software after correlation rather than by hardware before correlation. Only coarse phase and delay corrections (necessary to prevent decorrelation in the 10-s integration time) need be applied before correlation.

A block diagram of the interferometer is shown in Figure 1. The i.f. signal from the Tidbinbilla antenna is converted to baseband and limited to 0.5 MHz bandwidth using a standard VLBI converter. The microwave links between Parkes and Tidbinbilla consist of two bi-directional Telecom links installed for NASA for the Voyager Uranus encounter, and use an FM modulation system to give an 8 MHz bandwidth baseband input and output. The radio astronomy signal is sent over the microwave link from Tidbinbilla to Parkes, together with a 1 MHz pilot tone to monitor link phase variations; the spectrum of this signal is shown in Figure 2.

At Parkes the 1 MHz pilot tone is separated from the radio astronomy signal and mixed with it in the i.f. converter. This process cancels most of the phase variations introduced by the microwave link. The resulting signal is converted to 30 MHz centre frequency so that it may be input to the Parkes correlator (Ables et al. 1975). In the correlator frequency-convension chain, one of the local oscillators is replaced by a programmable Rockland Model 5100 synthesizer operating at about 1.25 MHz. The frequency of this synthesizer is adjusted every 1 s by the on-line software to remove phase variations due to the motion of the Earth. To prevent stochastic long-term phase drifts, the phase of the synthesizer is set to zero at the start of each 10 s integration. The resulting phase steps, together with fine phase variations due to apparent source motion, are subsequently removed by the off-line software.

The signal from the Parkes antenna is converted to baseband by a standard Parkes receiver and the correlator frequency-convension chain. It is then one-bit-sampled and shifted in delay by the delay unit. This unit has 256 μs as its finest increment,
and therefore needs only infrequent resetting (at source changes) by the on-line software.

The fine delay needed for source tracking is effectively provided by the correlator itself. The Tidbinbilla baseband signal is sampled in the correlator and applied to the $\Sigma$ input (see Ables et al. 1975), whilst the $S$ input is fed from the sampled and delayed Parkes signal. The correlator therefore produces a cross-correlation function (XCF) of the two signals over a delay range of 1024 delay steps, or slightly over 1 ms at 0.5 MHz bandwidth.

The on-line software estimates the position of the peak of the XCF, and transfers only 512 delay channels centred on that peak to the computer at the end of each integration. The 512-channel XCF is then Fourier-transformed to yield a 256-channel complex spectrum. For an ideal continuum source, with rectangular bandpasses, the XCF would resemble a narrow (one channel half-width to the zero-crossing points) sinc function in the centre of the delay range, from which a single amplitude and phase could be obtained. However, in practice the exact delay is not known until observations of calibrator sources have been analysed, and so in general the cross-correlation peak will not occur in the centre channel. Furthermore, a real, non-rectangular, bandpass will give a broader cross-correlation function. The resulting transformed spectrum will have a non-rectangular amplitude and a phase which might rotate through several turns across the bandpass. The measurement of this phase gradient allows an accurate determination of the baseline and source parameters. Thus delay tracking to a fraction of a correlator channel is accomplished in the transform domain by applying a phase gradient to the complex spectrum.

**First Fringes**

On the 27 June 1985 the first tests with the interferometer were conducted using the DSS45 34-m antenna at Tidbinbilla and the 64-m Parkes antenna at a frequency of 2.3 GHz. These test results were very successful, and fringes on the source 3C 273 were obtained on that day. A plot of the cross-correlation function obtained from these first observations is shown in Figure 3. Several other sources were also observed, in order to check that the phase rotation software was operating correctly over a range of positions in the sky. These first tests demonstrated the correctness of the design and implementation of the interferometer but they could not yield astrometric information since some of the timing hardware needed at Parkes was not yet complete. They also served to highlight a number of areas in which the phase and timing stability of the interferometer might be improved.

**Astronomical Potential**

The interferometer, which was designed primarily as a test-bed for developments in support of the Australia Telescope, has two principal astronomical functions:

1. Selection and astrometric measurements of calibration sources suitable for the Australia Telescope.
2. The study of compact galactic and extragalactic continuum and maser sources.

Each of these functions will now be discussed in turn.

![Figure 3 — The cross-correlation function of the first fringes obtained on the source 3C 273, shown as a function of delay. The modulus would resemble a sinc function, but the real part, shown here, contains a phase term which causes it to change sign close to zero delay.](https://www.cambridge.org/core/doi/10.1017/S1323358000017938)
simply by measuring the fringe visibility of the source at a number of hour angles. To measure the position of each source will require a source-switching technique, since the interferometer (at least in its Phase I operation) has only 10 min coherence time. (In this context, it should be noted that 'coherence time' refers only to quasi-random phase changes, since linear phase drifts may be removed by calibration.) The effect will be to measure the relative phase, and hence the relative position, between the target source and another calibrator source whose position is known accurately. The latter calibrator sources will initially be those measured in the VLBI experiments of D. L. Jauncey and other workers, but subsequent observations will use a bootstrap technique starting from our previously determined positions, together with any other astrometric positions that become available. In this way we hope to establish a reference framework for the AT covering the southern sky.

During our Phase I operation, the sensitivity limitation imposed by the 0.5 MHz bandwidth implies that we will only be able to measure positions of those reference sources which have flux densities greater than about 100 mJy. This limit, together with the VLBI results of Morabito et al. (1983), indicates that about 50% of strong flat-spectrum sources contain unresolved cores which will be visible to the Parkes-Tidbinbilla interferometer, suggesting that there are many hundreds of suitable calibrators accessible to the interferometer. Thus we are confident that we will be able to construct an extensive reference frame suitable for the AT.

Measurement of source structure
A single-baseline interferometer is clearly inferior to a synthesis array for the measurement of source structure. However, in the Southern Hemisphere there is at present no long-baseline synthesis array, and so there are many outstanding astronomical problems for which a single-baseline measurement is very much better than no measurement at all. In addition, there are some observations (e.g. mapping of unresolved OH and H2O maser spots, measurement of pulsar parallax and proper motion) for which the effectiveness of a single-baseline interferometer rivals that of a full synthesis array. The effectiveness of single-baseline interferometers for these latter experiments is well established (e.g. Norris and Booth 1981; Genzel et al. 1981; Lyne et al. 1982).

Single-baseline mapping of ordinary continuum sources cannot in general yield an unambiguous image, but it can decide between a limited range of alternative models. For example, the Parkes-Tidbinbilla interferometer would be a useful tool for the study of jets in active galaxies and quasars. It appears that such sources with compact structure often show jets when observed with VLBI. The Parkes-Tidbinbilla interferometer will be able to detect such jets and determine their orientation relative to the larger-scale structure.

Conclusion
The world's longest real-time interferometer has already produced its first fringes, and will soon reach completion of its initial phase of construction. It will then be capable of studying the sub-arcsec structure of southern sources at present inaccessible to any other real-time instrument. We hope to use the interferometer to construct a reference frame of calibrator sources in time for the commissioning of the Australia Telescope in 1988, and in addition tackle some problems of Southern Hemisphere astronomy which are at present beyond the reach of any other instrument.

This project would have remained a proposal had it not been for the support and encouragement of the late Alec Little, to whom we owe a great debt. We also wish to thank our colleagues, both at Parkes and Epping, for many helpful ideas and suggestions, and the Director and staff of the Tidbinbilla tracking station for their help and support.


Galactic and Extragalactic
A New Estimate of the Hubble Constant Using the Virgo Cluster Distance
N. Visvanathan, Mount Stromlo and Siding Spring Observatories, ANU

Abstract: A new distance modulus (31.23) to the Virgo cluster is derived using the distances to nearby galaxies given by Sandage and Tammann, de Vaucouleurs, ourselves and DDO observers. This when combined with the undisturbed mean Virgo cluster velocity 1182 km s⁻¹, gives a value for the global Hubble constant as 67 ±4 km s⁻¹Mpc⁻¹.