An ‘X-Banded’ Tidbinbilla Interferometer

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Abstract: The recent upgrading of the Tidbinbilla two-element interferometer to simultaneous S-band (2.3 GHz) and X-band (8.4 GHz) operation has provided a powerful new astronomical facility for weak radio source measurement in the Southern Hemisphere. The new X-band system has a minimum fringe spacing of 38 arcsec, and about the same positional measurement capability (approximately 2 arcsec) and sensitivity (1 s rms noise of 10 mJy) as the previous S-band system. However, the far lower confusion limit will allow detection and accurate positional measurements for sources as weak as a few millijanskys. This capability will be invaluable for observations of radio stars, X-ray sources and other weak, compact radio sources.

Introduction

The Tidbinbilla interferometer has proved a valuable Southern Hemisphere astronomical tool, particularly for the measurement of accurate positions (~2 arcsec rms) of compact radio sources for the purpose of optical identifications (e.g. Jauncey et al. 1982). The instrument has been operating for several years at a frequency of 2.3 GHz (S-band); this paper describes its upgrading to additional operation of 8.4 GHz (X-band).

A fuller description of the 2.3 GHz instrument and its use may be found in Batty et al. (1982); here we summarize its main features. The interferometer makes use of the 64 m (DSS43) and 34 m (DSS42) antennas of the NASA Deep Space Network tracking station at Tidbinbilla, near Canberra. These antennas are normally used for tracking deep space vehicles, such as the Voyager spacecraft. The interferometer uses the existing ultra-low-noise-maser first-stage receivers on the antennas, together with a dedicated system of electronics interfaced to a small computer system (Rayner and Batty 1980) for data acquisition and reduction. This ‘piggy-back’ mode of operation means that the full sensitivity advantages of the NASA systems are utilized, while the interferometer may be quickly brought into operation to make efficient use of the limited time available when the antennas are not tracking spacecraft.

The system baseline is fixed at 195 m (north-south), yielding a minimum 2.3 GHz lobe spacing of about 2.3 arcmin; the antenna feeds are circularly polarized (usually right-hand), the system temperature at the zenith is about 20 K and the i.f. bandwidth is 12 MHz, which gives a 1 s rms noise level of ~10 mJy. Positions accurate to about 2 arcsec may be routinely measured for sources stronger than about 50 to 100 mJy; below this flux limit the accuracy degrades owing to the effects of confusion, which is a vector of ~6 mJy, except near the galactic plane, where the confusion can be much worse. To date the observation program has concentrated on compact extragalactic objects from the Parkes catalogue, most of which are free of the above problems.

After the system performance was proven at 2.3 GHz it became clear that there would be considerable advantages in extending the system to operate at 8.4 GHz, the other frequency for which maser receivers were available on the two antennas. At 8.4 GHz the confusion limit should be about two orders of magnitude smaller; this should in principle enable accurate position measurements at the arcsecond level to be made on sources as weak as a few millijanskys. In the next section we describe the new 8.4 GHz interferometer system, which was designed and constructed at CSIRO Division of Radiophysics and Jet Propulsion Laboratory, U.S.A., (JPL) and commissioned late in 1985.

The New 8.4 GHz System

The parameters of the 8.4 GHz system are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre frequency</td>
<td>8.420 GHz (λ = 3.56 cm)</td>
</tr>
<tr>
<td>Polarization</td>
<td>Right circular</td>
</tr>
<tr>
<td>Primary beamwidth</td>
<td>~3 arcmin</td>
</tr>
<tr>
<td>I.F. bandwidth</td>
<td>50 MHz (see text)</td>
</tr>
<tr>
<td>System temperature</td>
<td>~25 K at zenith</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>~50 mJy in 1 s (5σ)</td>
</tr>
<tr>
<td>Minimum lobe spacing</td>
<td>38 arcsec</td>
</tr>
</tbody>
</table>

A block diagram of the new system is shown in Figure 1. It may be operated in parallel with the existing 2.3 GHz system, since the antennas are equipped with dual-frequency feed systems which are effectively concentric. All the additional hardware and observing and reduction software has been designed to accommodate simultaneous 2.3 and 8.4 GHz operation.

The first-stage 8.4 GHz masers have nominal bandwidths of ~100 MHz; however, the measured bandwidth of the maser on the 34 m antenna is slightly less and therefore limits the usable bandwidth of the whole system. With this in mind the 8.4 GHz interferometer electronics were designed for a full 100 MHz bandwidth but limited in normal operation to 50 MHz by filters.
The maser outputs are amplified by GaAs FET amplifiers and converted at the antennas to a first intermediate frequency centred at 312 MHz. The 8108 MHz first local oscillators are phase-locked to the existing 96.52 MHz phase-stable references used in the 2.3 GHz system. Thus no additional phase-stabilizing systems were required for the new system. The first i.f. signals are fed through low-loss coaxial cables to the main control building, where second converters produce a second intermediate frequency at 70 MHz; this frequency was chosen to be compatible with the existing 2.3 GHz system. Fixed equalizers compensate for the differential loss across the i.f. bandpass.

As with the existing system, analogue delay lines are used to compensate for the geometric path delay between antennas; for the design bandwidth of 100 MHz this proved easier and more efficient to implement than digital devices. The delay lines (see Figure 2) consist of 10 switched segments with binary-stepped lengths configured in a ‘complementary cross-over’ mode as described by Hills et al. (1973). Because of the large fractional bandwidth required (20 to 120 MHz) these include special attenuation and dispersion compensation. Most delay segments consist of RG253 low-loss cable while most bypass segments consist of special high-loss UT141L semi-rigid cable. Identical fixed cable equalizers in each i.f. channel compensate for the overall loss/frequency characteristics of the delay line unit. Together the delay lines and equalizers give a phase match and amplitude flatness of \( \pm 2^\circ \) and \( \pm 0.2 \) dB respectively for the two i.f. channels across the full 100 MHz design bandwidth.

As for the 2.3 GHz system, most of the delay line lengths are integral multiples of a wavelength at 70 MHz so as to produce zero i.f. phase change when switched. Because of the wide bandwidth, however, the three shortest delay increments must be less than one wavelength at 70 MHz. These were chosen to be sub-multiples of a wavelength and the resulting phase change was compensated for by a digitally controlled phase shifter in the second local oscillator. This phase shifter also provides fast (100 Hz) phase switching of one i.f. signal. As for the existing system, no lobe rotator is included; all fringe fitting is carried out in off-line software.
The i.f. signal processing and data acquisition are similar to those of the 2.3 GHz system, but redesigned to accommodate the wider bandwidth and provide slightly more flexibility. The system bandwidth may be limited to 50 MHz (the normal mode) or 12 MHz by means of switchable filters. Correlation is performed by FET analog correlators as before, but with improved bandwidth and stability. These have a response which is flat to within ~0.2 dB over the 20 to 120 MHz design bandpass. The correlator outputs are synchronously detected at 100 Hz and sampled at 1 Hz by integrating 16 bit A/D converters. The data handling and reduction are identical to those for the 2.3 GHz system.

Performance and Calibration
Preliminary observations with the new system have shown that it has substantially met its design goals. The sensitivity appears to be within a factor of ≤1.3 of that expected theoretically. In one trial the phase stability was evaluated by comparison with the 2.3 GHz system; there was no substantial difference in the (scaled) phase scatter or drift over time scales of minutes to several hours, indicating that a typical rms phase scatter of about 10° to 15° might be expected on calibrators. This probably indicates that tropospheric phase excursions over these time scales, together with baseline uncertainties, will limit the normally attainable positional accuracy to about 1 or 2 arcseconds for either system. The 8.4 GHz system will therefore probably offer no improvement in positional accuracy, but the full accuracy should be attainable to very low flux density levels, perhaps ~1 mJy. To achieve this level of performance the stability of the system must allow coherent integrations over periods of at least 20 min; preliminary tests indicate that this is achieved.

Calibration of the new system may prove to be a little more difficult than the old, although it appears that the existing geometric baseline solution should be adequate. At 8.4 GHz antenna pointing becomes more critical; this is not important (to first order) for position measurements, but flux calibration may be difficult until a full antenna pointing solution is obtained.

In addition, there appear to be minor misalignments between the 2.3 and 8.4 GHz system beams.

With the higher resolution finding suitable position and flux calibrators may be a problem, since extended radio structure undetected at lower resolution may be present in many sources. At present potential calibrators are being drawn from a working list of compact objects with accurate VLA, VLBI or optical positions; a sizable fraction of these have already proved unsuitable for use at 2.3 GHz for the above reasons or because of incorrect previous optical identifications.

Astronomical Potential
Because of its high sensitivity and low confusion limit the instrument will be suited for observations of weak, compact sources. In particular, it should be ideal for positional and flux measurements of galactic radio stars and radio counterparts of X-ray sources, most of which have flux densities below a few tens of millijanskys. The arcsecond positional accuracy at fluxes of a few millijanskys will enable unambiguous identification or virtually all objects above the sensitivity limit. Thus the instrument should also prove ideal for studies of the radio emission from the outer planets.

In addition, the availability of simultaneous 2.3 and 8.4 GHz data will prove invaluable for studies of transient phenomena, such as X-ray bursting sources and flare stars. With the current data acquisition software the maximum time resolution is ~1 s (giving an rms noise level of ~10 mJy); the ability to discern rapidly varying spectral structure makes it a unique instrument for such studies.

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