REMARKS ON IMAGE RECONSTRUCTION FOR THE MEDIUM AND LONG BASELINES IN THE AUSTRALIA TELESCOPE

1. INTRODUCTION

This note contains some remarks on continuum image reconstruction for the medium and long baselines of the AT. The problem in image reconstruction for these baselines is to find some means of accounting for atmospheric phase fluctuations which are independent from telescope to telescope and which completely destroy the phase coherence of the incoming radiation. At lower frequencies ($\lesssim 1$ GHz) ionospheric disturbances dominate; at higher frequencies, tropospheric effects are more important.

Two main techniques can be used to reduce and substantially eliminate the effects of these atmospheric fluctuations - hybrid mapping (or adaptive calibration), and phase calibration by means of a nearby unresolved reference source (or phase referencing).

These are briefly discussed in the following two sections, and a possible data reduction scheme is introduced in the final section.

2. HYBRID MAPPING

The dramatic improvement in the quality of VLBI maps in the last five years has come about through hybrid mapping, that is the use of closure relations in the interferometer phase and amplitude to constrain the range of structures consistent with the data (Rogers et al. 1974, Readhead and Wilkinson 1978, Cotton 1979, Readhead et al. 1980). Basic to these methods is the recognition that effects which corrupt the phase and amplitude observables (i.e. the visibilities) can be assumed to be telescope related.

Recently more general algorithms for adaptive calibration have been developed by Schwab (1980) and Cornwell and Wilkinson (1981) for use with 'unstable' interferometers. Their approaches are based on correcting errors occurring at individual telescopes rather than adjusting the interferometer phases and amplitudes in accordance with the closure quantities. The Cornwell and Wilkinson method allows for varying signal-to-noise ratios in the visibility data on each baseline as well as different degrees of instability at each telescope. The method has been used to great effect with MERLIN and the VLA.

A trial map derived from modelfitting (or in later iterations, from delta functions generated by CLEAN) is used to estimate the true visibilities on each baseline for each observed data point (as in earlier closure methods). These are compared with the observed visibilities and optimum estimates made of the gain and phase deviations which have occurred at each telescope to produce the observed corrupted data (see Cornwell and Wilkinson 1981 for details of one of these schemes). The observed data are corrected and processed via conventional mapping programmes using the CLEAN algorithm to produce a new trial map. The process is repeated with corrections being applied to the modified data from the previous iteration. The corrections tend to zero as the process converges.

Inherent to all hybrid mapping methods is the requirement that, at all hour angles, the source be sufficiently strong to give a reasonable signal-to-noise ratio on each baseline in an integration time shorter than the coherence time, typically 10-20 minutes at 6 to 21cm. The coherence time is set primarily by the atmosphere provided the local oscillator system is made coherent by radio link (medium baselines) or satellite link or hydrogen maser oscillators (long baselines - see ATDOC104).

At 2.3 GHz, hybrid mapping will be effective with the medium baselines of the AT if sources have a moderately unresolved component in their structure stronger than about 20 mJy at all hour angles on all baselines, while for the long baselines this component has to be stronger than about 100 mJy. These limits are calculated under the following assumptions:

1) the integration time is 10 minutes, the I.F. bandwidth is 50 MHz, and telescope aperture efficiencies are 50%.
2) the Culgoora 6km array can be phased-up to give the equivalent collecting area of a 49m antenna,
3) the medium baseline array consists of Culgoora, Siding Spring (22m), Parkes and Tidbinbilla whose system temperatures are taken to be 30K,
4) the long baseline array consists of the medium baseline array plus Fleurs, Hobart, Alice Springs and Carnarvon. The system temperatures of the small telescopes at 2.3 GHz are taken to be 50K. The 10 "small-small" combinations are not included because they are not sensitive enough.

The limits increase to 100 mJy and 500 mJy for the medium and long baselines respectively for the 2 MHz bandwidth currently recorded with VLBI techniques.

The dynamic range of a hybrid map will be somewhat worse than that of a full phase map (see next section) even though the strong point-like component acts as a phase reference for weaker structure in the source. This is to be expected since the closure quantities do not constrain the map as strongly as do the true amplitudes and phases.

3. PHASE REFERENCING

Aperture synthesis using phase referencing is in standard use at the VLA as a means of reducing (primarily) atmospheric errors to manageable proportions before further manipulation with adaptive calibration techniques. Telescopes are switched between reference source and program source rapidly enough that tropospheric or ionospheric variations in the phase of the program source are monitored via deviations from zero phase in the calibrator, and then corrected. Some experience in VLBI phase referencing has been gained at MIT (Marcaide, private communication) which indicates that it is no simple task to make the phase transfers accurately.

There are a number of conditions to be satisfied before phase referencing can be successfully carried out:

1) the structure of the reference source must be determined beforehand to sufficient accuracy that its phase behaviour as a function of hour angle is known.

2) the reference source must be bright enough that (i) a hybrid map can be made and (ii) the integration time on the reference source does not have to be long. For the medium baselines of the AT this means $S \gtrsim 40$ mJy, and for the long baselines $S \gtrsim 200$ mJy. The extra factor of 2 compared to the limits given in the last section is to allow for shorter integration times on the reference source.

3) baselines must be known to $\pm \sim 1.6\ \lambda$ in order to transfer phase to 10° accuracy from a reference source 1° away on the sky. Proportionally greater accuracy is required for reference sources further away. Phase errors deriving from incorrect baselines will intrude on the phases of the program source, but can be recognised by their sinusoidal behaviour as a function of hour angle and eliminated. Following the April 1982 VLBI campaign, baselines accurate to < 40 cm have been established; this will be improved in future observations.

Source counts at 2.7 GHz (Wall and Cooke 1975) have shown that there should be 1 source brighter than 40 mJy every 0.4 square degrees on the sky, i.e. within $\sim 0\overset{\circ}{.}4$ of any point on the sky, and 1 source brighter than 200 mJy every 3 square degrees or within $\sim 1°$ of any point on the sky.

For the long baselines it is essential that the independent oscillators remain in phase during one cycle of switching between program and reference source. This requires either hydrogen masers at each station or a local oscillator link via AUSSAT.

Although phase referencing will not be easy, particularly on the long baselines, the rewards are potentially high; the rms noise after a 12 hour coherent integration lies in the region of 100 to 200 μJy at 2.3 GHz for both the 4 station medium baseline array and the 8 station Australian VLBI network (for 50 MHz bandwidth). From this it is clear that the small antennas contribute very little to the overall sensitivity; the noise in the map will vary from size scale to size scale, reflecting the different noise in each baseline. In principle, integrations from one day to the next, to increase signal to noise, would also be possible, as is now done with the WSRT and the VLA. This opens up a range of weak structure that is inaccessible using hybrid mapping techniques since the latter require a strong, relatively compact feature in the field of view of the interferometer that is detectable in some basic short integration time. The point source detection limit for a phase referenced measurement is about 600 μJy for 50 MHz bandwidth. A somewhat higher detection limit applies to weak sources in the field of a strong source mapped with hybrid techniques; however a strong source must be present in this case.

4. DATA PROCESSING

A possible scheme for data processing (adapted from Schilizzi *et al*, NFRA Internal Technical Report 165) is shown in Figure 1.

Two paths are shown, one for baseline calibration, the other for astronomical data. Following a (12-hour) calibrator session, run every one to a few weeks, the geodetically useful quantities derived from interferometry, phase and delay, can be input to geodetic software (e.g. from Haystack/NASA/MIT) in order to derive the accurate baselines required for phase referencing and the other geophysically interesting parameters. On the astronomical side, it is anticipated that phase referencing will involve a first pass through the calibrator observations to determine a phase table which, after removal of any effects of calibrator structure, can be interpolated to allow the appropriate phase rotation of the program source during integration in a second pass through the data. Further phase adjustment via adaptive calibration techniques now in use for hybrid mapping would follow the correction of the phases.

The calibrated amplitudes and phases as a function of time would form the "standard product" of the Australia Telescope Processing Facility (ATPF) at Culgoora. It is likely that phase referencing will be gradually introduced as an option; in its absence the "standard" phases will only be useful in closure.

References:

Rogers, A.E.E., *et al.* (1974), Astrophysical Journal, Vol. 193, p.293.

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Cotton, W.D., (1979), Astronomical Journal, Vol. 84, p.1122.

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Schwab, F.R., (1980), Proc. 1980 International Optical Computing Conference, Society Photo-Optical Engineers (SPIE), Vol. 231, p.18.

Cornwell, T.J. and Wilkinson, P.N., (1981), Monthly Notices of the Royal Astronomical Society, Vol. 196, p.1067.

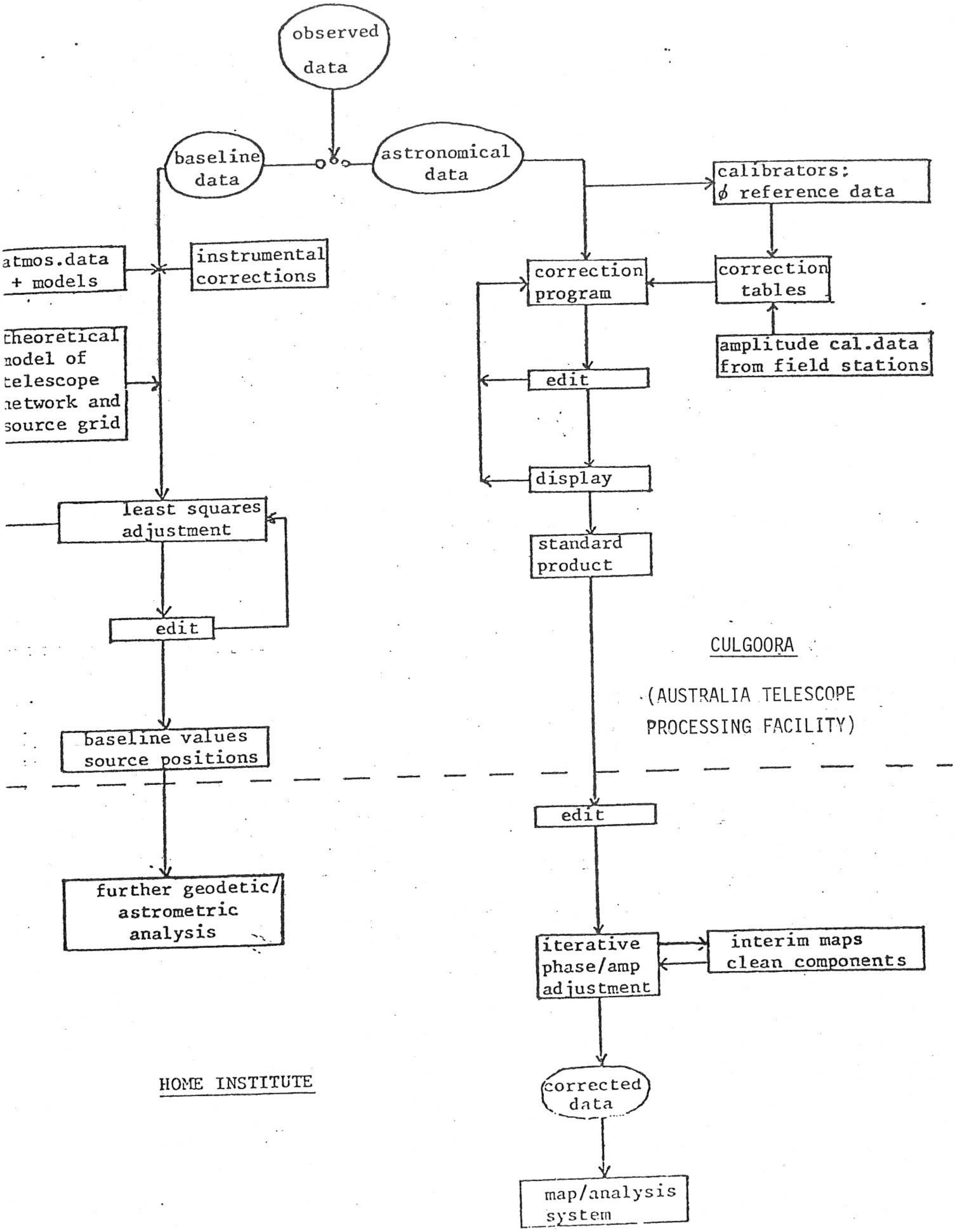

Figure 1:
Off-line data flow for the AT ~~for~~ medium and long baselines.