RPN

AT/23.4/011

A SOFTWARE SOLUTION TO THE LO DOPPLER PROBLEM

R.P.Norris

31 January 1985

1.0 INTRODUCTION

In the discussions on the problem of shifting the AT LO's for Doppler corrections (AT/20.2/008, AT/23.4/008, ad hoc meeting of 15 January), a software solution was discussed and rejected. Here I propose that the software solution considered then was indeed inadequate, but that a more sophisticated solution is possible which overcomes all of the objections raised. The scheme proposed here is not original: the European VLBI network (EVN) already uses it (using Method (a) below) for spectral line observations, and it seems to present no problems except for a slight reduction in usable bandwidth, as discussed below.

This technique has not yet been discussed adequately, and this note should be regarded as the start of a discussion rather than as a firm proposal.

2.0 THE TECHNIQUE

In essence the scheme proposed here involves the following steps:

1. During the observations, all LO's are kept fixed (other than for fringe rotation) so that a spectral feature is allowed to slide up and down the bandpass as the Earth rotates.

2. The data are then corrected for the bandpass response, using a previous calibration observation.

3. The doppler correction is then applied to the data, by shifting the data in frequency. In order to avoid smearing or channel discontinuities, this shifting is actually performed in the Fourier domain, so that the sequence is: (a) FFT the data to the complex delay domain; (b) multiply by a phase gradient (the transform of a shift in frequency): (c) FFT back to to the frequency domain.

Method (a) below (as used for the EVN) implements this scheme directly. Method (b) below avoids the additional FFT's by doing both the bandpass correction and the doppler correction in the delay domain, before the data are transformed to the frequency domain in the correlator.

3.0 METHOD (A)

The easiest way of implementing the scheme is to do the doppler correction within AIPS. This has the following advantages:

1. It's intuitively easy to see what's going on.
2. It's easy to get at - the code can be fiddled around with after the data have been taken.
3. It's easy to omit this correction when it's not needed (e.g. for continuum observations).
4. It's copying a technique that's already been tried and tested (by the EVN).

and the following disadvantages:

1. It requires an additional 2 FFT's per uv point. Since the correction will be used on spectral line data, which already stretch the computing resources, this may be significant.
2. The raw data from the AT is non-standard, in the sense that it needs this correction before it can be run through standard AIPS.

4.0 METHOD (B)

An alternative way is to do the correction within the correlator, before the data are transformed to the frequency domain. Note, however, that it must be done <u>after</u> the bandpass correction, because otherwise any bumps in the bandpass will be applied to the wrong channel. Therefore the bandpass correction must also be done in the delay domain. Thus, when a calibrator is observed, the integrated bandpass response must be transformed back to the delay domain and stored. On subsequent 'astronomical' observations, the cross-correlation function must be (a) convolved with the transform of the bandpass response, and then (b) multiplied by a phase gradient which is calculated from the doppler shift required. Thus the corrected cross-correlation function (XCF) X is obtained from the observed XCF Y by applying:

$$X(\tau) = e^{i\delta\tau} \int Y(\tau') B(\tau-\tau') d\tau'$$

where δ is the required doppler shift and $B(\tau)$ is the FT of the calibrated bandpass response.

This method has the following disadvantages:

1. It requires more computing in the correlator (but not as much computing in total as method (a)).

2. It's a new technique: we'll have to run simulations to check that there are no problems with it.

3. The calibration can't easily be fiddled about with after the observations, although on the other hand it would be straightforward to write an AIPS task to undo and redo it.

and the following advantages:

1. It requires far less computing power in total.

2. The resulting data can go straight into standard AIPS.

5.0 POSSIBLE OBJECTIONS

A real disadvantage of the technique is that it reduces the available bandwidth slightly, since the band-edges at one time will be added into other channels at other times. The reduction in bandwidth is a maximum of 8kHz per GHz observing frequency, or 3% at 500kHz bandwidth at L-band.

An objection that might be raised is that a given map will contain data from different spectral channels, and so any bandpass miscalibration will degrade the dynamic range. In reply to this, it should be noted that the bandpass calibration should remove any such channel-to-channel variations, since it is done <u>before</u> the doppler correction. Furthermore, I suggest that bandpasses tend to be amongst the most stable parts of the system (at least on the time-scale of calibration observations - say tens of minutes) and that the bandpass calibration can be done extremely well, so that any bumps in the bandpass should be almost eliminated. In addition, if there are any second-order residuals, they can be removed by selfcal (since they are antenna-based). Ultimately, however, this suggestion needs to be tested by simulation.

Another possible objection is an uneasiness about spectral features being shifted by fractions of channels. However, it should be noted that, because the shift is done in the fourier domain, where the information in each spectral channel is spread across the function, there is no special significance about an individual channel, and no blurring or dilution occurs regardless of the amount of shift.

6.0 CONCLUSION

The technique described offers a simple way of overcoming the doppler problem, with no loss of dynamic range or spectral resolution. Its only disadvantages appear to be:

1. A slight reduction in usable bandwidth.

2. A slight increase in required computing power, either in the off-line reduction (method(a)) or in the correlator (method(b)).

If this technique wins general support, I propose to write the necessary software to run simulations for testing the technique.