AT MEMORANDA SERIES: Correlator System
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PROPOSED AT SPECTRAL-LINE CORRELATION SYSTEM

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Report of working group set up by AT Scientific Objectives Committee to investigate a correlation system

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1. (a) A spectral-line system should be planned with maximum sensitivity in mind. Accordingly, dual polarization input should be assumed, and provision should be made for 2-bit correlation. Whether this should be an option with the sacrifice of half the number of channels, as in the Parkes correlator, or whether a permanent 'hard-wired' feature might be more economical, should be explored.

(b) For observations of maser lines, the use of Hanning smoothing is essential, and should be assumed for considerations of desired frequency resolution. It should be applicable as an option in 'real' time (this would facilitate real-time monitoring).

2. The general form of spectral-line correlator should allow all the channels to be used either together (giving maximum spectral resolution for a selected bandwidth) or grouped into independent sets (at least four, as are available at Parkes). Typical modes of operation would be:

(a) two identical sets with orthogonal polarizations (see 1(a))

(b) four identical sets to obtain all polarization parameters

(c) sets centred at different frequencies within the IF passband (e.g. simultaneous observations of two or more 1.6 GHz ground-state OH transitions, 22 GHz NH3 transitions, or recombination lines).

(d) sets with different bandwidths and frequency resolutions (e.g. for observation of spectra containing both narrow maser lines and broad 'thermal' lines).

3. For simplicity the correlator bandwidths should be 2^nMHz, with n an integer.

4. The boundary values for the parameters of a spectral-line correlator are defined by the requirements for observations of 22 GHz H_2O masers, 1.6 GHz OH masers, and 115 GHz CO emission:

(a) H_2O maser observations require a velocity resolution of 0.1 km/s (7.5 kHz) over a velocity band of up to 100 km/s (7.5 MHz)

(b) OH maser observations require a similar velocity resolution (0.6 kHz). While an instantaneous band of 90 km/s (0.5 MHz) may be adequate for most galactic projects, observations of the galactic centre region and of other galaxies would be most efficiently made with a bandwidth of 360 km/s (2 MHz).

(c) A bandwidth of at least 100 MHz (260 km/s) would be needed if extragalactic CO observations were to be attempted.

5. The principle of 'recirculation' appears to be necessary to provide high frequency resolution for the lower bandwidths with a moderate number of correlator channels.

6. With points (1) - (5) taken into account, the ideal configuration would be based on a total of 256 spectral correlator channels plus recirculation. If 2-bit correlation can be attained without sacrificing channels, then for a 6-element array the basic number of complex correlations is 15 x 256 = 3840. The correlator configuration is (assuming 15 baselines, 2 polarizations, Hanning, and recirculation):

Bandwidth (MHz)	Spectral 'channels' per input polarization	Max. resolution with two polarizations and Hanning (kHz)
128	128	2000
64	256	500
32	512	125
16	1024	31.3
8	2048	7.8
4	4096	2.0
2	8192	0.5

(a) For a particular bandwidth the resolution could be improved by a factor of two by accepting only one input polarization; conversely, all four polarizations could be simultaneously observed with a degradation of resolution by the same factor.

(b) If spectral continuity is not critical (e.g. if the spectrum is a series of discrete lines rather than a broad continuous feature), improved resolution can be achieved for a specific bandwidth by using a set of bands offset in frequency from each other. For example, the table shows a total of 128 channels available for a bandwidth of 128 MHz. However, this bandwidth could also be obtained using two sets of 64 MHz bands set 64 MHz apart; the 128 MHz width would then be covered by 256 channels.

(c) At the low bandwidths, the number of channels may seem prohibitively large in terms of number of synthesized maps to be made. However, it is envisaged that only channels of specific interest will be selected for reduction (i.e. those containing maser lines for instance). In many cases, these channels will be known in advance. At the same time some provision should be made (e.g. summed auto-correlation spectra) for forming sensitive spectra over the full primary beam for the duration of the observations. These would form the basis for channel selection during the reduction phase.

(d) The process of recirculation is ideal for spectral line observations because the small bandwidths will be used at the lower frequencies. Here the velocity/frequency ratio will be higher, and therefore more channels are required to achieve the desired velocity resolution.

(e) Use of 2-bit correlation may require a doubling of the required number of complex correlator channels to obtain the listed frequency resolutions.

(f) With reference to (4), the listed specifications provide the following:

(i) for CO extragalactic observations in a 128 MHz (330 km/s) band with a resolution of 5.2 km/s, or in two contiguous 128 MHz bands with a resolution of 10.4 km/s (with two input polarizations this would require a total of four bands). For galactic observations the 32 MHz (83 km/s) band provides adequate resolution (0.33 km/s) for HII regions, while the 16 MHz (42 km/s) band offers a resolution (0.08 km/s) ideal for cold dust clouds.

(ii) for H_2O, the 8 MHz band provides a width of 107 km/s at a resolution of 0.1 km/s.

(iii) for 1.6 GHz OH, the 2 MHz band provides a width of 360 km/s at a resolution of 0.09 km/s. Use of two pair of bands, one set at 1665 MHz, the other at 1667 MHz, would permit simultaneous observations of these lines with a resolution of 0.18 km/s.

7. The configuration set out in 6. may be economically impractical; for the 'worst-case' data rate, there are 245,760 complex correlations (15 x 8192 x 2) c/f 89856 (351 x 256 x 1) for the VLA. As a minimum system, a recirculation system ranging from 64 MHz (32 channels) to 1 MHz (2048 channels) might be acceptable. The main consequences would be an insufficient bandwidth for extragalactic CO observations, and marginal best resolution at OH and H_2O frequencies for reasonable bandwidths. On the other hand, the data rates would be lowered and the number of correlations reduced to 61440.

8. If the recirculation technique is not used, then to satisfy the conditions set out in 6. the number of required complex correlators would be 15 x 2 x 8192. If this were reduced by a factor of 4, the resolution available in a 2 MHz band is inadequate for OH observations. However, this could be improved by using a smaller bandpass (e.g. 0.5 MHz) at the expense of velocity coverage.

9. Autocorrelation spectra for each antenna is desirable. They would be useful for bandpass calibration and obtaining integrated spectra as discussed in 6(c). If they were obtained at the same time as the spectral-line observations, the number of telescope 'correlations' increases from 15 to 21.

10. A modified autocorrelation technique is useful to simplify the data reduction of point-source spectral measurements. For this there must be the capability of adding together the relevant correctly-delayed IF's from all antennas (a 'tied array' mode), splitting the signal and autocorrelating it in the spectrometer. The spectrum of the point source is then obtained with the sensitivity of the whole array.

<u>Other Considerations</u>

1. A continuum correlator with multiband facilities to avoid bandwidth smearing with the use of large bands should be available. This would enable good continuum data to be taken at the same time as high spectral resolution data. It could be considered as an independent set of the spectral-line correlator or as a separate system.

2. Frequency flexibility would be improved if the two polarization channels have independent LO's on the front end. However, in this mode only one polarization would be available at each frequency. If both polarizations are required at each frequency, then four IF channels would be necessary. This would be most useful for simultaneous observations with two receivers. The data links from telescope to computer must have a capability consistent with the RF bandwidths and number of IF channels.

3. The data load is proportional to the total number of frequency channels observed. In order to minimize the amount of stored data, provision should be made to select specific channel ranges for storage.