Note on the efficiency of the GMRT FX correlator. May 15 1990

From: Ravi, A. Pramesh Rao

The efficiency of the FX implementation of the correlator is known to be significantly lower than that of the XF implementation and a proper understanding of the trade-offs available is necessary in order to obtain the optimal sensitivity for a particular observation. Although the choices are limited when the widest bandwiths and maximum resolution are required, the extra processing capacity that becomes available when these requirements are relaxed should be put to optimum use. An early decision on the strategy to be adopted in feeding the antenna signals to the FFT machines is necessary in order to be able to specify clearly as to what is expected of the hardware buffers/multiplexers that interface the samplers/delay lines with the FFT cards. This note is a result of some preliminary thinking on the problem and is based on the results of short simulations. Although the results of the simulations have not been fully understood, this note has been writted so that it can form the starting point for understanding the problem. No quantitative results are quoted from the simulations because we have not performed the simulations for long enough computer time in order to get the accuracy of ≈1% that should be reached in the computed efficiency.

This note assumes that 2048-point FFTs can routinely be performed by the correlator hardware with no sacrifice in the number of IFs handled. This should be possible since the FFT cards can clearly handle the processing required. The input and output data streams from the card will have to be properly routed (multiplexed) to enable 2048 point FFTs, and this will hopefully be implemented so that the processing capacity is not wasted.

When continuum visibility alone is required, our simulations have shown, as expected, that the length of the FFT computed does not affect the sensitivity. Also, overlap between the successive data sequences does not improve the correlator efficiency. The FX correlator can be expected to provide the same sensitivity as an XF correlator except for any degradation owing to the finite wordlength effects in the FFT machines. Hence, for continuum observations, the FFT length can be just sufficient to allow interference rejection. In the presence of strong interference, where it is necessary to have low sidelobe responses for the channel filters, it would be advisable to resort to windowing of the time sequences. In this case, the adjacent sequences would have to be suitably overlapped in order not to degrade the efficiency; this is possible only if the total continuum bandwidths required are less than 16 MHz.

When operating on 16 MHz bandwidth signals sampled at 32 MHz rates, and when the maximum spectral resolution of 1024 points is required, the FX correlator performance cannot be enhanced.

At these bandwidths, if the required number of channels is less than 1024, the choices available are

(i) Length of the FFTs,
(ii) Channel averaging/smoothing in spectral domain.

Our simulations confirm the expectation that both options are equivalent in terms of the correlator efficiency. But the channel filter frequency responses will be different. In this situation it is better to perform FFTs of the maximum possible 2048-points and average/smooth the spectra in order to obtain required number of channels. In this way, the channel filter funtions will be closer to rectangles than $sinc^2$, and the sidelobes will be lower.

When the bandwidths are less than 16 MHz, the FFT machines can still be made to operate at 32 MHz throughput rates and hence the adjacent time sequences input to the FFT machines can now be overlapped.

If the full 1024 frequency channels are required, the choices available are only

(i) overlap percentage.

Our simulations indicate that when flat spectrum noise is input to an FX auto-correlator and the overlap is 0%, the averaged power spectra have SNR in the individual channels that equal the value of SQRT(m), where m sequences of 2048-points were input to the FX correlator. If the sequences overlap, the SNR in the individual channel power estimate improves above this value of SQRT(m), where the total time sequence length processed is 2048 x m. The SNR of the continuum channel does not improve with overlap indicating that the fluctuations in the spectral channels are not independent. These results are surprising and we speculate below on the cause for this effect. It may be noted that the N/2-point spectrum obtained as a result of averaging the power spectra which are obtained as squares of the N-point FFTs of overlapped sequences has an SNR in each channel that is better than the SNR one would obtain if one computed the FFT of the N/2-lag auto-correlation obtained using the same time sequence. For each N-point time sequence, the FX correlator effectively computes the correlations at up to N-lags (averaging over N-i products at the i^{th} lag; i=0 to N-1) and tapers the correlations with a rectangular window giving the N/2-point resolution. As the overlap is increased, the number of independent products accumulated in each of the N-lags increases to the maximum possible and hence the spectral sensitivity improves. For maximum overlap, the N/2-point power spectrum produced by the FX machine is the DFT of triangularly tapered correlations at up to N-lags (N +ve and N -ve) with all the lags being computed as the average of mN independent products (mN is the total number of independent temporal data points processed) and with the DFT being computed at only alternate points. The foregoing conjecture must be verified by sufficiently accurate simulations which can be quantitatively compared with the expectations. The undersampling in the DFT domain implies only that one cannot perform an IDFT and obtain the correlation coefficients at all the lags. The undersampling of the spectrum obviously will not affect the spectral estimates. The simulations and the foregoing discussion leads us to suggest that the maximum possible overlap should be resorted to.

If a reduced number of channels suffice, the choices are multiple :

(i) FFT length

(ii) Channel averaging/smoothing

(iii) Windowing the time sequence

(iv) Overlap between successive time sequences

(v) Zeropadding

Zeropadding that doubles the length of the time sequence is a must if one wishes to transform back to the correlation coefficient domain in order to perform the Van Vleck correction. This could be neccessary while observing very strong sources where correlation coefficients approach unity. Otherwise, the 4-bit quantization is not expected to require this correction. Zeropadding will also provide an interpolated spectrum which will be useful if other techniques like channel averaging/smoothing or windowing of the t me sequence is not used to improve the $(\mathrm{sinc})^2$ shape of the channel filters. The latter alternative is more attractive and should be the option selected. This point is of special importance when observing spectral lines that are narrower than the channel-to-channel spacing.

Irrespective of the required spectral resolution, FFT lengths of the maximum possible (2048) should probably always be computed. This leaves a choice of three options ~~(ii) to~~ (iv).

Windowing is generally recommended wherever overlap is possible since the shape of the channel filters and sidelobe levels can be very much improved. A possible strategy would be to window the time sequences so that the resolution is reduced by a factor of ≈2 (with the overlap ensuring no degradation of sensitivity) and then average the spectral channels to produce the required spectral resolution. Increasing the overlap improves the number of independent products that go into the longer lags and hence increasing the overlap is useful only if high spectral resolution is required. Simulations could determine the correlator efficiency as a function of overlap for a particular choice of overlap (50 and 75%) & window (an optimal window has to be selected for each overlap) & channel-averaging.

It appears that the best strategy would be to always run the correlator to compute 2048-point FFTs. Whenever bandwidths that are submultiples of 16 MHz are used, option to overlap the successive sequences input to the FFT machines by 50% and, when possible, 75% could be provided. Whenever the spectral resolution required is a submultiple of 1024, the input sequence can be windowed (when overlap allows) to reduce the 1024-point resolution by a factor of 2. Further spectral smoothing can be achieved by channel averaging.