Delay decorrelation corrections for VLBA data within AIPS

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Abstract

Recent VLBA imaging tests on DA 193 have shown the need for delay decorrelation amplitude corrections in order to achieve images with very high dynamic range (Cornwell, Kemball and Benson, 1995, VLBA Scientific Memo. 11). This memorandum describes the two major sources of decorrelation for VLBA correlated data and how they are corrected within AIPS.

1 Introduction

Data processed by the VLBA correlator may require small corrections for two sources of baseline-based, or non-closing amplitude errors. The first is connected with spectral pre-averaging within the correlator and the second with mis-alignment of the FFT segments on input to the FX correlation stage. As the need for these corrections was revealed by high dynamic range imaging tests they were added incrementally to AIPS, starting with the 15JAN95 release. The 15JAN95 release allowed a correction for spectral averaging losses, as described in the associated AIPS Letter. In the 15JUL95 release the ability to correct for the much smaller mis-alignment losses has been added. As both sources of amplitude loss increase with larger delay errors, they are referred to as delay decorrelation losses in what follows.

Both are described here, along with practical information concerning how they are applied within AIPS. Empirical measurements of these effects are also described along with Monte Carlo simulations of the mis-alignment losses.

2 Delay decorrelation loss factors

2.1 Spectral averaging decorrelation

The VLBA correlator may optionally pre-average cross-power data over frequency immediately after cross-multiplication. In a typical case an FFT size of 512 may be used and the data averaged down to 16 spectral channels on output. Due to the presence of residual delays, averaging over frequency introduces non-closing amplitude errors. The amplitude correction can only be made in subsequent post-processing once the residual delays have been determined in fringe-fitting. For an idealized, flat continuum spectrum with a linear phase slope, the pre-average of N points is represented by the sum:

$$\frac{1}{N}\sum_{k=0}^{N-1} e^{j(\phi_0+\delta\omega\tau k)} = \frac{1}{N}\frac{\sin(\frac{N\delta\omega\tau}{2})}{\sin(\frac{\delta\omega\tau}{2})} e^{\phi_0+\frac{N-1}{2}\delta\omega\tau}$$

where, ϕ_0 is the phase at the lower edge of the band, $\delta\omega$ is the bandwidth of an individual spectral channel in the cross-power data and τ is the residual delay across the band. The amplitude loss factor takes the expected discrete $\frac{\sin(x)}{x}$ form. The spectral averaging losses increase in importance with increasing BBC filter bandwidth.

2.2 Alignment or segmentation decorrelation

Second-order amplitude losses are introduced in an FX correlator due to mis-alignment of the data segments going into the FFT as a result of residual delay errors. For an idealized, flat continuum spectrum the amplitude loss as a function of delay is given by the self-convolution of the weighting function used in the time domain in the FFT. For example, for uniform weighting the delay decorrelation function is a unit trapezoid with zeros at $\pm N_{fft}$, where N_{fft} is the FFT size in bits. Hanning weighting has been used in the past at the VLBA correlator. The self-convolution functions for both uniform and Hanning weighting functions are shown in Fig. 1. It is necessary to use the digitized correlator representation of the weighting function in the calculation of the self-convolution and this is implicit in what follows.

3 Measurements of the VLBA delay decorrelation

The delay decorrelation losses have been measured empirically using uv-data taken as part of the DA 193 imaging tests which are reported elsewhere (Cornwell, Kemball and Benson, 1995, VLBA Scientific Memo. 11). To measure the decorrelation, these data were observed with both 8 MHz and 16 MHz BBC filters and subsequently correlated over a range of clock offsets with both Hanning and uniform FFT weighting. Fringe searches were used to derive a dataset with negligible delay errors in IF 1, which was then essentially unaffected by delay decorrelation losses. The delay decorrelation losses for other correlation runs were then obtained by a point-by-point division of the correlated uv-data by the data with perfect clocks and the ratio averaged over time and frequency. Only the inner 75% of IF 1 was used in these tests. The use of non-redundant clock offsets allowed a near uniform sampling of the decorrelation over a range of residual delay.

The decorrelation loss factor as a function of delay is shown in Fig. 2 for one such a test using 16 MHz data with clock errors spanning 2000 ns and a spectral averaging factor of 16. The solid line shows the $\sim \frac{\sin(x)}{x}$ function describing spectral averaging losses while the dashed line is the total amplitude loss obtained by including alignment or segmentation decorrelation. The slower fall off in alignment decorrelation due to the shape of the Hanning self-convolution function over that for uniform weighting near zero lag is evident. Fig. 3 shows the amplitude loss factors for 8 MHz data, again for the case of uniform and Hanning weighting and a spectral averaging factor of 16. The solid and dashed lines describe spectral averaging and segmentation losses respectively, as before. In both Fig. 2 and Fig. 3 the theoretical expressions for the loss factors are used. Residual decorrelation losses may be caused by higher order unmodelled decorrelation or inherent limits on this type of decorrelation measurement. The residual effects are small however and further work on this question is in progress. It must be noted that VLBA clock errors are typically less than 250 ns, and may be considerably better in some cases. The range of clock errors shown in Fig. 3 is that found for one run of the test DA 193 observations.

Returning to Fig. 2, the form of the alignment decorrelation can be confirmed by dividing the measured total decorrelation by the spectral averaging loss factor. The result for the 16 MHz data is shown in Fig. 4, and is in general agreement with the expected trapezoid and Hanning self-convolution functions for uniform and Hanning weighting respectively. The self-convolution functions are shown by the solid lines in each plot.

For reference, Monte Carlo simulations of a simple FX correlator were performed, and the resulting alignment decorrelation for Hanning and uniform weighting is shown in Fig. 5. These simulations used a flat noise spectrum, and the functional form of the alignment decorrelation is confirmed.

4 Implementation within AIPS

These corrections are not implemented in AIPS releases prior to 15JAN95.

4.1 15JAN95

As described in the associated AIPS Letter, this release corrects for spectral averaging decorrelation only. This correction is activated if the array name in the AN table is VLBA and, in addition, the AN table contains a keyword, SPEC_AVG, set to the spectral averaging factor defined in Section 2.1. The correction is then made whenever delay corrections are applied (eg. SPLIT). The spectral averaging factor can be determined from the number of frequency channels in the catalog header after FITLD, N_{frq}, and the FFT size N_{fft}, which is stored in the MC table as,

$$N = \frac{N_{fft}}{2\ N_{frq}}$$

Sample TABED input parameters required to set SPEC_AVG are given below:

> INNAME = file_name	Input uv-file name
> INCLASS = class	uv-file class
> INSEQ = n	Sequence number
> INDISK = m	Disk volume
> INEXT = 'AN'	Modify AN table keyword
> INVERS = 1	AN table 1
> OUTN=INNA; OUTCL=INCL	Set output file to input
> OUTSEQ=INSEQ; OUTDI=INDI	
> OUTVERS = INVERS	Modify AN 1
> BCOUNT=1; ECOUNT=0	Copy all AN entries
> OPTYPE= 'KEY'	Add keyword
> APARM=0; APARM(4)=4	Add integer keyword
> KEYWORD = 'SPEC_AVG'	Keyword
> KEYVAL = 16,0	To set a spec. avg. factor of 16
> KEYSTRNG=	
> TIMERANG=0	

4.2 15JUL95

This release incorporates the second order alignment decorrelation correction in addition to the spectral averaging correction. This has been implemented in a more general and robust framework than the previous release by introducing a new correlation parameter frequency (CQ) table. This table contains information about how each IF was originally correlated and insures that such information is preserved throughout post-processing.

FITLD will create the the CQ table under the control of the new adverb DELCORR. If it is not created then the delay decorrelation corrections are disabled (see Section 5). A new task FXVLB can also be used to create the CQ table but must be run before the frequency structure of the uv-data file is modified by data selection or averaging (eg. UVCOP or AVSPC). FXVLB takes only the uv-data file name as input. If the array name in the AN table is VLBA and the CQ table is present then the delay decorrelation corrections will be automatically made whenever delay corrections are subsequently applied (eg. SPLIT). A warning will be given if delay calibration is applied for VLBA data without a CQ table. The corrections are at present intended for the calibration of multi-source uv-data only.

The AIPS command EXPLAIN FXVLB provides further information.

5 General notes

1. Spectral averaging in the correlator is not recommended for spectral line projects, as these delay decorrelation corrections are exact only for flat continuum spectra. Note however that the smaller bandwidths typically used in spectral line observations minimize alignment losses due to the increased time interval per bit, and consequently the smaller fractional alignment error over the FFT size as a whole.
2. For 16 MHz, 32 frequency channels of 500 kHz per channel are recommended to reduce spectral averaging losses.
3. The outer frequency channels in each IF may be affected by non-closing errors due to the assumption of flat spectral response, and may need to be discarded for very high dynamic range imaging.
4. The differential polarization delay offset at the reference antenna must be corrected before applying decorrelation corrections to polarization data so that the cross-hand correlations are properly corrected.

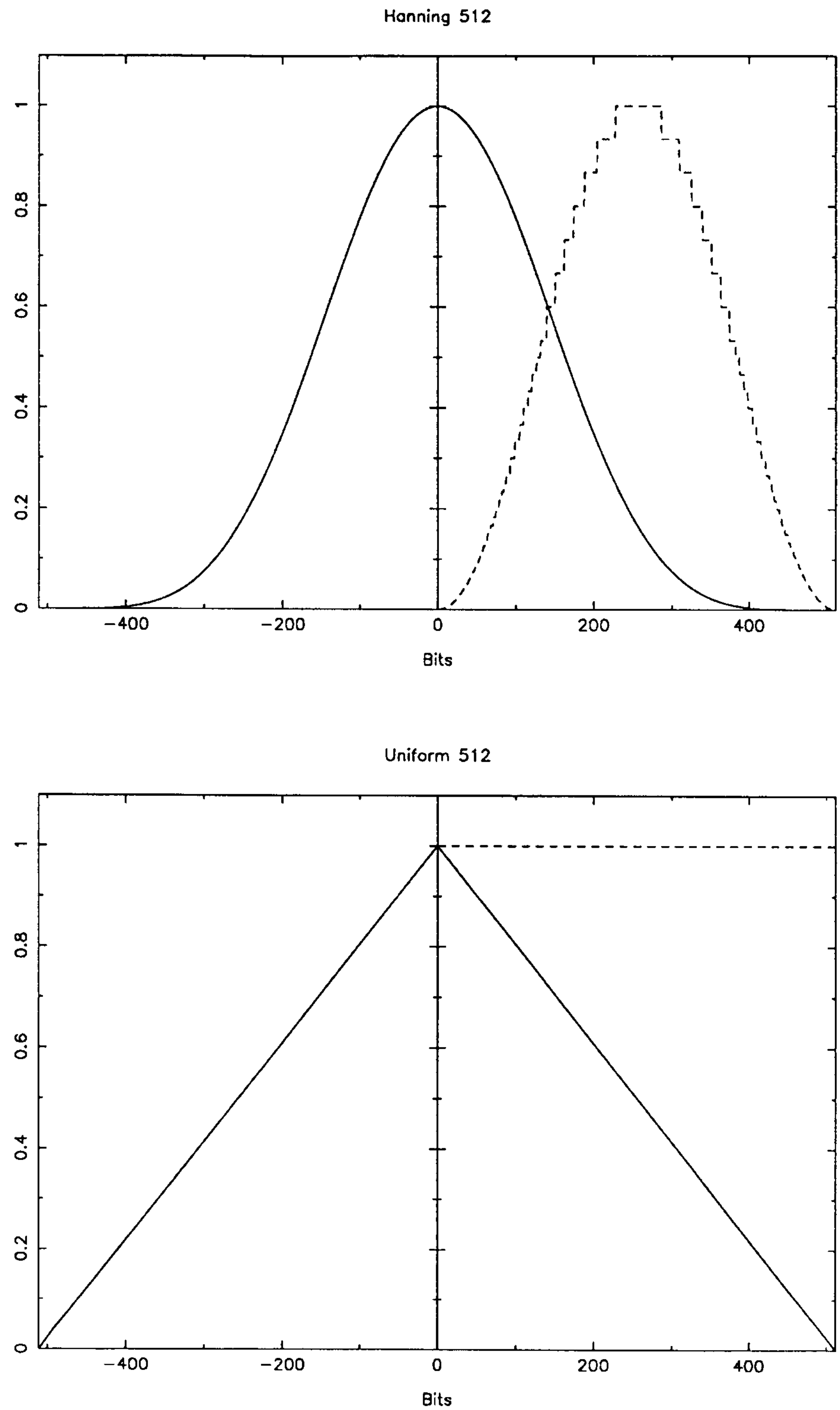
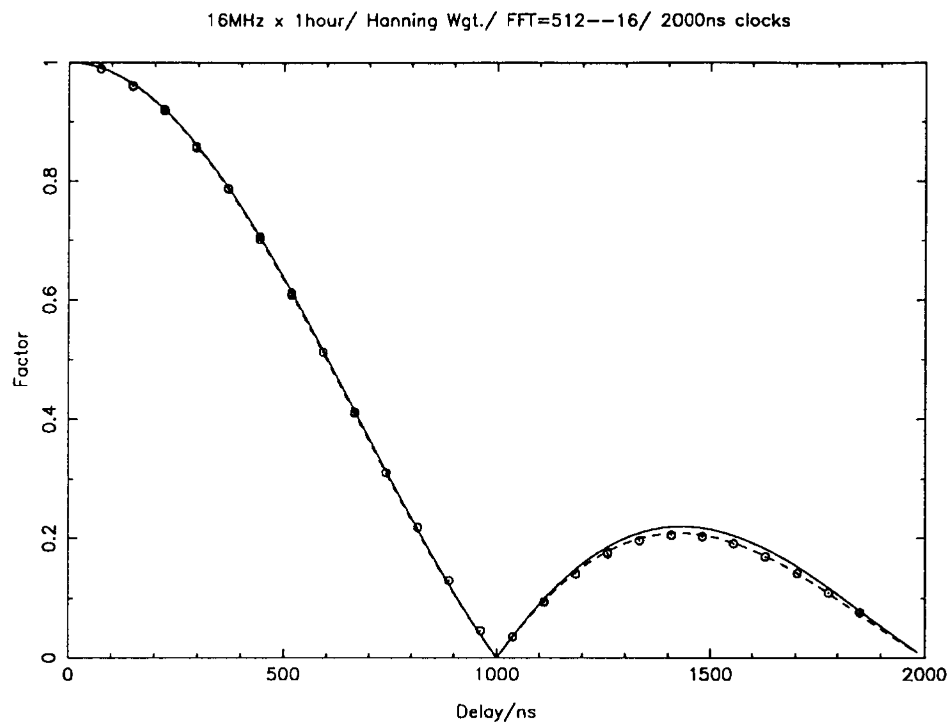


Figure 1: FFT weighting function (dashed line) as implemented in the VLBA correlator for $N_{fft} = 512$, and its self-convolution (solid line), as a function of bit offset, for both Hanning and Uniform weighting.



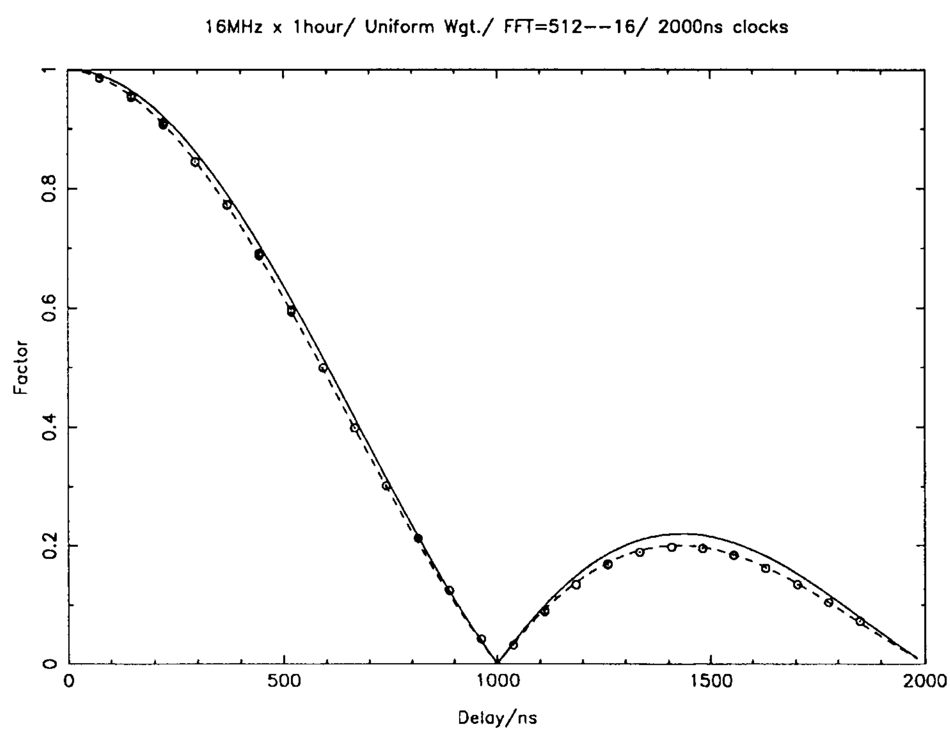
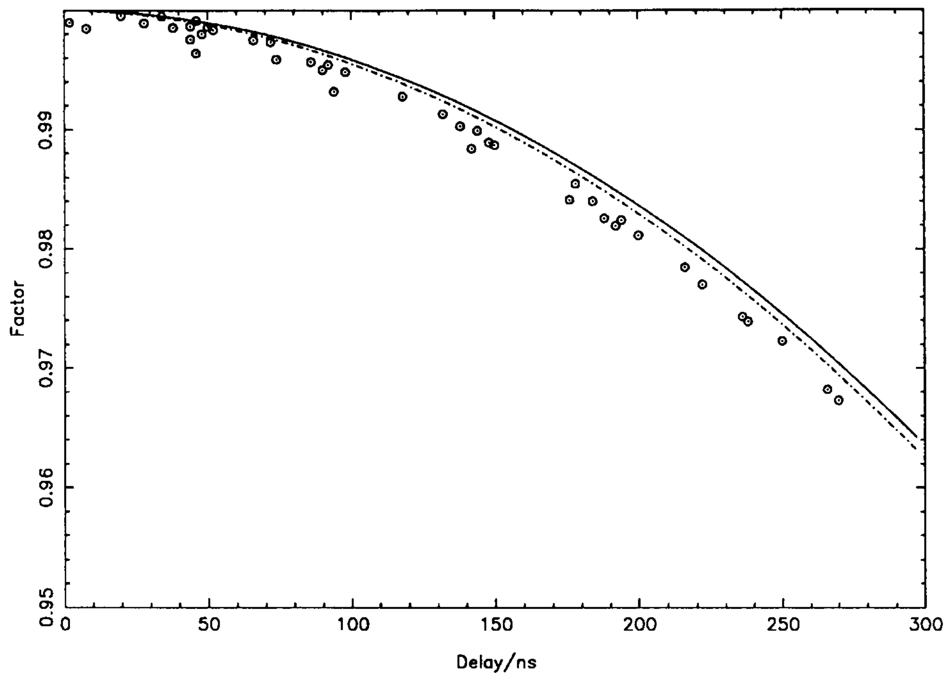


Figure 2: Measured delay decorrelation for 16 MHz data with clock errors of 2000 ns and $N = 16$. Both uniform and Hanning weighted data are presented. The spectral averaging loss (solid) line and total correction including the segmentation loss (dashed line) are plotted.

8MHz x 12hour/ Hann. Wgt./ FFT=512--16/ GPS clocks



8MHz x 12hour/ Uniform Wgt./ FFT=512--16/ GPS clocks

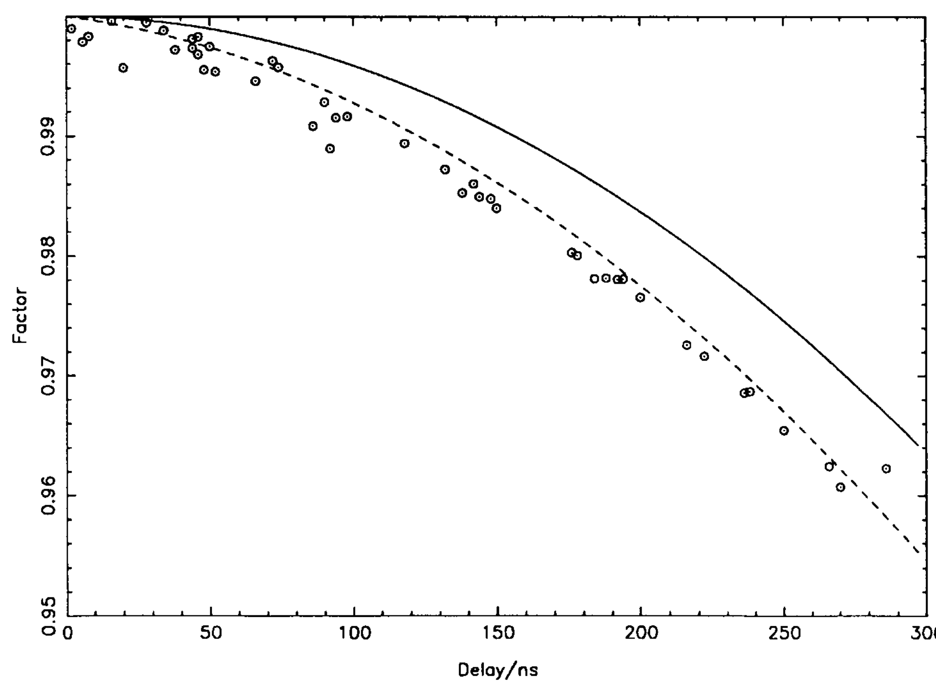
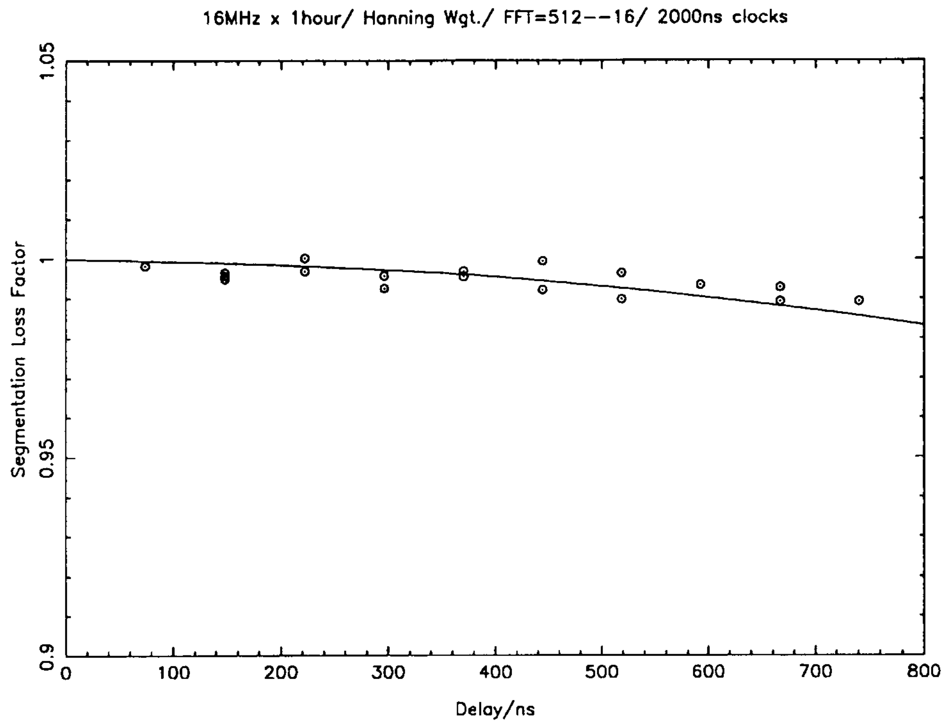


Figure 3: Measured delay decorrelation for 8 MHz data with clock errors of 270 ns and $N = 16$. Both uniform and Hanning weighted data are presented. The spectral averaging loss (solid) line and total correction including the segmentation loss (dashed line) are plotted.



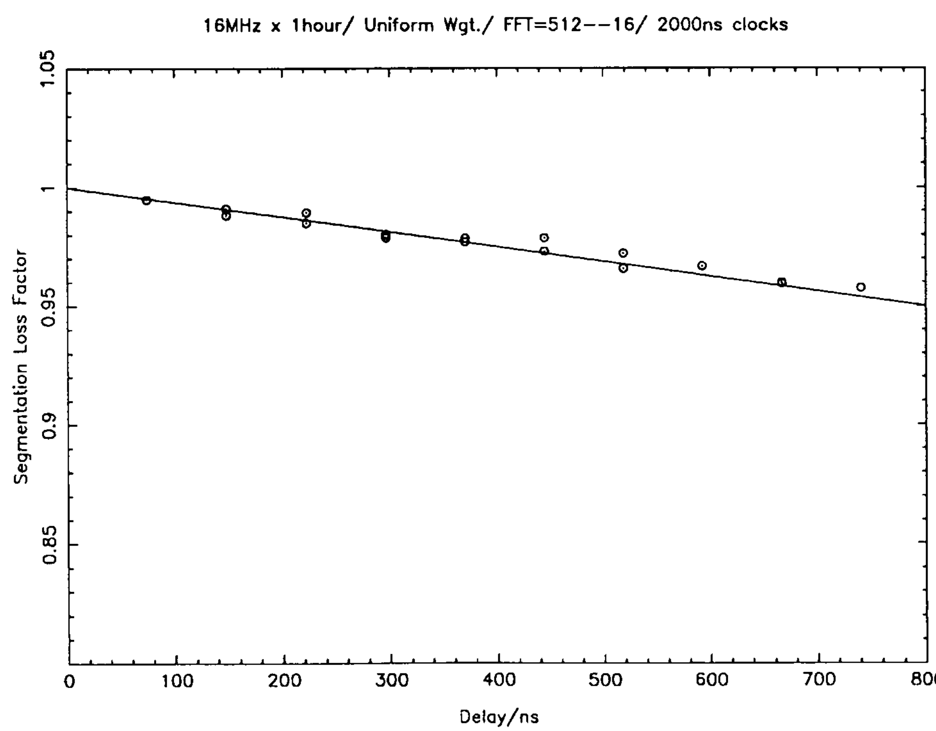
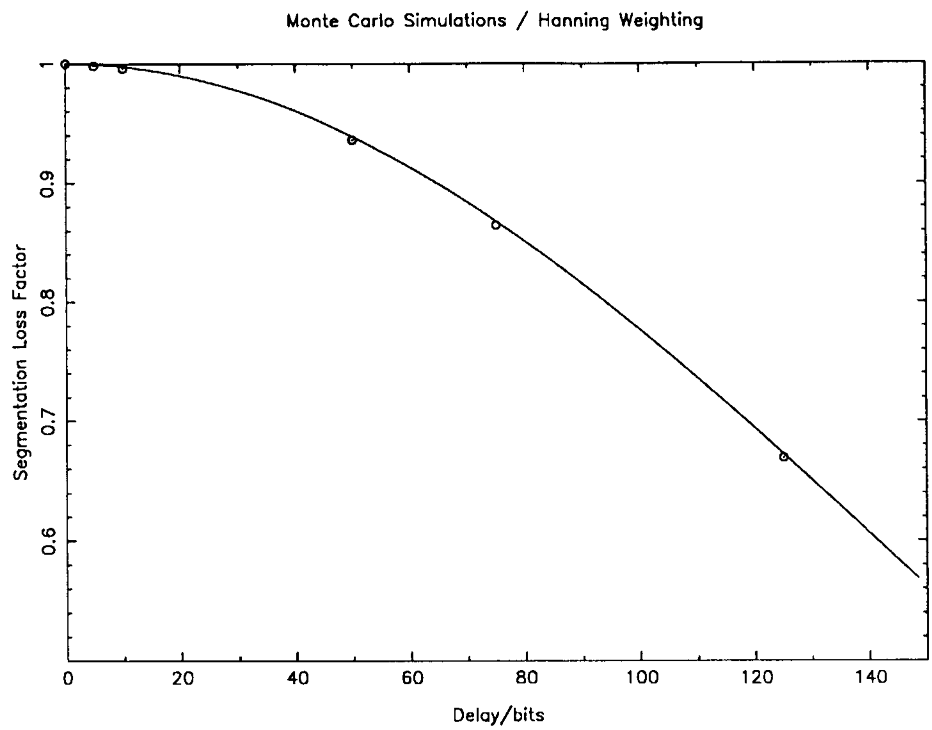


Figure 4: Measured alignment or segmentation decorrelation using the data presented in Fig. 2 corrected for spectral averaging losses. Both uniform and Hanning weighted data are presented with the theoretical value plotted as a solid line. Data above 800 ns are excluded due to low SNR and outliers near the *Sinc* null at 1000 ns.



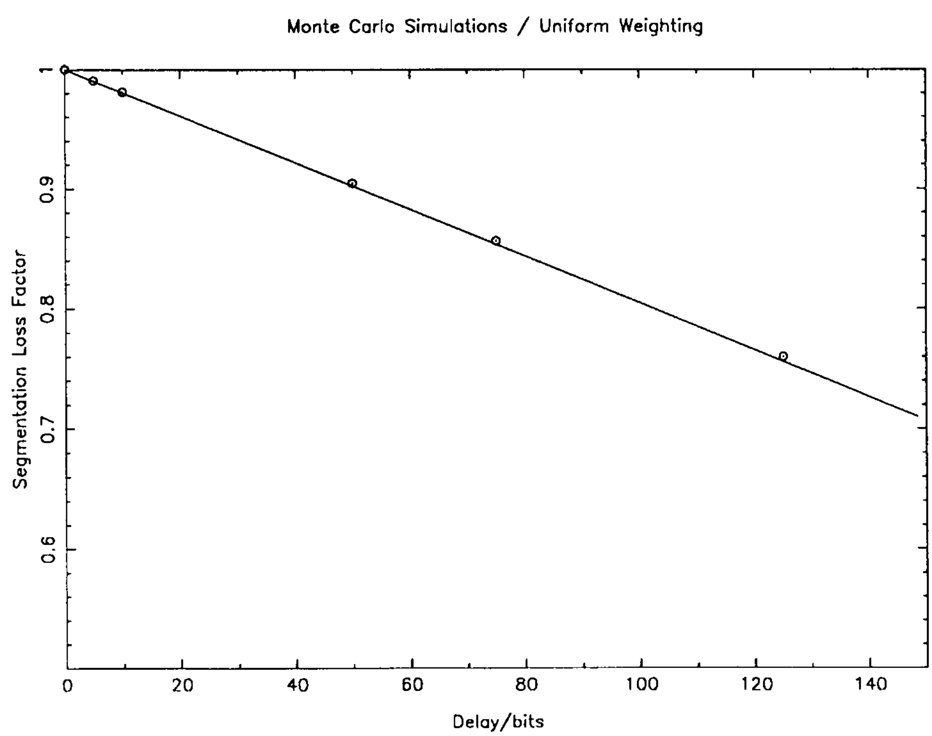


Figure 5: Segmentation or alignment decorrelation for uniform and Hanning weighted data, as obtained by Monte Carlo simulation of a simple FX correlator with flat spectrum input noise. An FFT size of 512 bits is used here.