Appendix I: Acoustic Bit Correction™

High quality digital audio sound often incorporates long words (many bits). Both high resolution A/D converters (18 bits or more) and signal processing equipment (digital mixers, equalizers, reverb and more) generate longer words than those supported by standards (such as the 16 bit CD format). A straightforward word length reduction severely deteriorates the musical fine detail of low level signals by introducing distortions and a noise floor that is modulated by the signal.

Proper dithering serves to eliminate the distortions and noise modulation effects. The desirability of such improvement is unquestionable but is coupled with increasing noise floor. Noise shaping is based on shifting the noise from high sensitivity frequency regions to less sensitive ones. That process is based on psychoacoustic research. A "stand alone" noise shaper does not improve distortions and noise modulation problems. Lavry Engineering's Acoustic Bit Correction incorporates both concepts to reduce distortion and noise modulation and shape the noise psychoacoustically.

Customer feedback and further studies taught us two interesting facts:

a. Various data compression schemes require the dither to have flat frequency response characteristics.

b. Recording engineers' preference of dither type (high pass or flat) and noise shaping curves often depends on characteristics of the music involved.

The Model 3000S offers High Pass or Flat Dither type and four noise-shaping curves.

Model 3000S allows the user to use dither with or without noise shaping. Operating noise shapers without dither is undesirable so the unit automatically shuts the noise shaper off when dither is off. Using dither (with or without noise shaping) requires user discretion. Ideal data transfer and processing should retain long word length. A single word length reduction (and therefore dithering and noise shaping) should take place last.

Figure 1 shows a -100 dB 1 kHz 24 bit tone truncated to 16 bits. The distortion is severe. Figure 2 shows the same tone with high-pass dither only. The distortion is gone, and the tone's level appears at a true -100 dB. Figure three shows the same tone with Acoustic Bit Correction applied. Notice what the addition of noise-shaping to the dither does to the noise floor in the ear's most sensitive mid-range area (approx. 2kHz to 8 kHz).

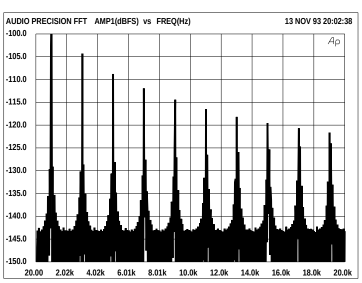

Fig. 1- truncation only

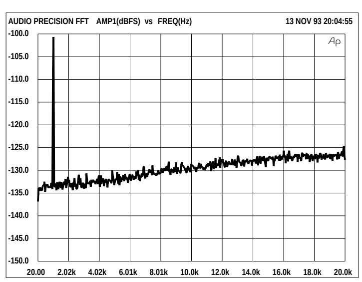

Fig. 2 - high-pass dither

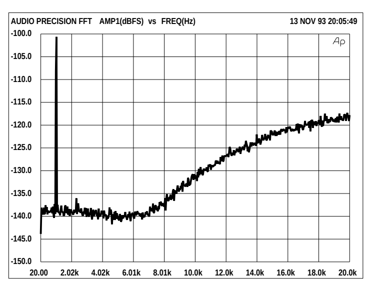

Fig. 3 - Acoustic Bit Correction High Pass- NS2

A number of mathematical and psychoacoustic researchers introduced two concepts for sonic improvement: dithering and noise shaping. Credit is due to L. Fielder of Dolby Labs for providing the basis for various noise shaping curves. The reasons for triangle PDF dither have been explained by S. P. Lipshitz and J. Vanderkooy of the University of Toronto. Additional publications by M. Gerzon, P. G. Craven, J. R. Stuart and J. R. Wilson (all from the United Kingdom) and J. Goodwin (from the U.S.A.) shed light on this complex subject.

Dithered noise shaping technology has been incorporated into a handful of hardware devices. While all are based on the same concepts, some perform better than others. After simulating and listening to all available public domain algorithms, Lavry Engineering came to some conclusions in forming a basis for Acoustic Bit Correction. The principal conclusions are:

a. The practice of greatly amplifying low level signals to determine triangular flat PDF (probability density function) dither reveals the effectiveness of distortion and noise modulation elimination. This practice yields misleading results when testing unflattened dithers and/or noise shapers. It conflicts directly with L. Fielder’s findings showing completely different threshold detectability curves for quiet and loud levels. Noise shaping listening tests must be done at "reasonable" volume levels.

b. Given the above requirement, our listening tests concluded a strong preference for "triangle high pass" dither (this dither is produced by simultaneously adding a new random number and subtracting the previous value). Such dither is frequency-shaped to carry more high frequency energy (the energy content at low frequencies is minimal).

c. Listening tests revealed a preference for smoothly varying noise shaping curves. Peaks and notches seem to irritate the listener (admittedly while turning the volume up). In addition, despite the temptation to optimize the noise shaping curve to the average listener’s hearing threshold, given a significant variation from listener to listener requires reasonable compromises in tailoring such a curve. In other words, smooth the curve.

The improvements offered by dither and noise shaping vary with source material and final word length. An A/B/X test at 16 bit level, requires a quiet environment and low level (loudness) audio. The listener must resist the temptation to turn the volume up to unreasonable levels. The practice of truncating to short word length (8-12 bits) should be avoided, although the Model 3000S performs this admirably. The ideal noise shaping curve may be irritating at loud levels. (Model 3000S's 8 bit noise shaping curves are based on a different curve).

Lavry Engineering's listening tests were based on test tones and repeating loops of quiet passages of various material (mostly classical music) with flat amplifier response. Listening to test tones was straightforward: we used the Model 3000S test tone generator mode switching the Acoustic Bit Correction on and off. The frequency and amplitude programmability was very useful.

Listening to music required 18 to 20 bit material. Distortion present at the 16 bit input word can not be removed by dither. The algorithm was functional (to a lesser degree) from a noise shaping standpoint, but distortion removal did not take place (the data distortion content due to the previous truncation was interpreted as signal). Acoustic Bit Correction is aimed at correcting truncation problems associated with the shortening of word length.

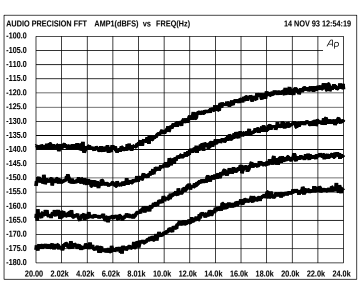

Fig. 4 - Acoustic Bit Correction
16 (top), 18, 20, and 22 bits
no input signal

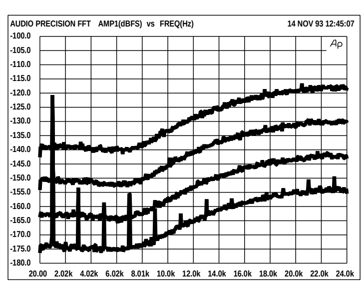

Fig. 5 - ABC HP-NS2
16 (top), 18, 20, and 22 bits
-120 dB 1 kHz sine tone

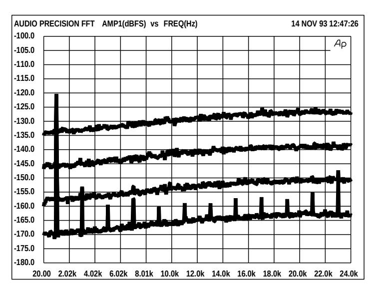

Fig. 6 - dither only
16 (top), 18, 20, and 22 bits
-120 dB 1 kHz sine tone

Acoustic Bit Correction may be used with words of lengths wider than 16 bits. Figure 4 shows the noise floor of Acoustic Bit Correction (High Pass, NS2) without a signal at 16, 18, 20, and 22 bit wordlengths. Note the curved noise-floor with lowest level in the ear’s most sensitive mid-range region.

Figure 5 shows Acoustic Bit Correction (High Pass, NS2) applied to a 24 bit input, reducing to 16, 18, 20, and 22 bit output widths. Notice that there is no noise modulation present.

Figure 6 shows the effect of high-pass triangular dither only. The more coherent data in the dithered bits, the better the dithering process works. Note that dithering from 24 bits to 22 bits has a lower noise floor but more visible distortion components than dithering to a shorter word length, due to fewer bits in the portion of the word being truncated.

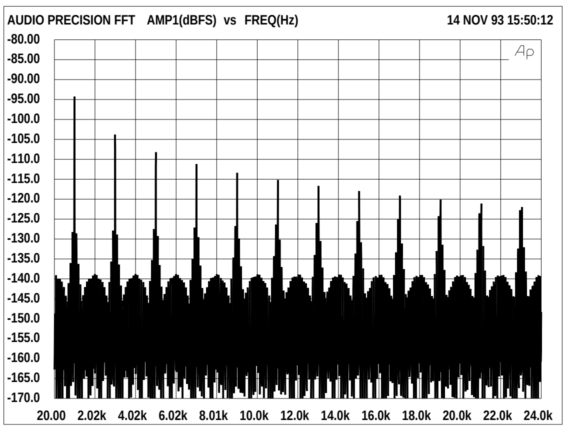

Fig. 7- 16 bit input signal -100 dB
truncation by previous processing

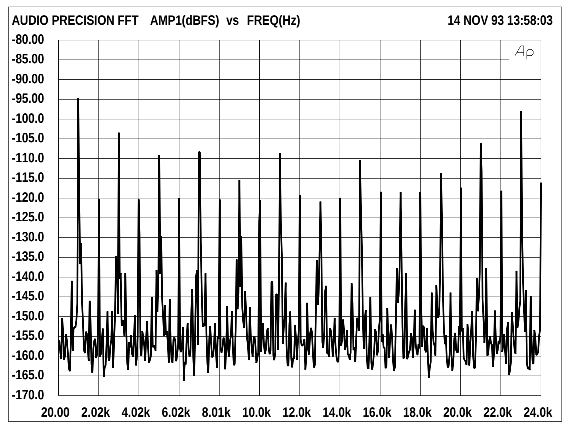

Fig. 8- 16 bit input signal -100 dB
additional processing and truncation

Should dither be applied to input signals of 16 bit word length? Figure 7 shows a -100 dB tone of 16 bit word width with no dither or noise shaping. Note the presence of all of the odd harmonics, created when the truncation process turned the tone into a 1 lsb square wave.

Figure 8 shows the result of applying additional processing to this signal, and truncating the result, thereby creating additional distortion components.

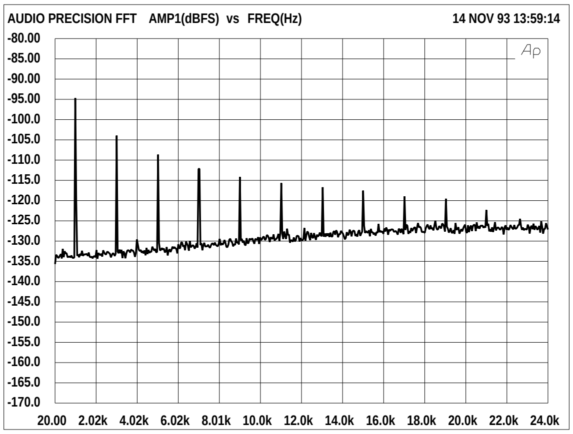

Fig. 9- 16 bit input signal -100 dB
high pass dither applied

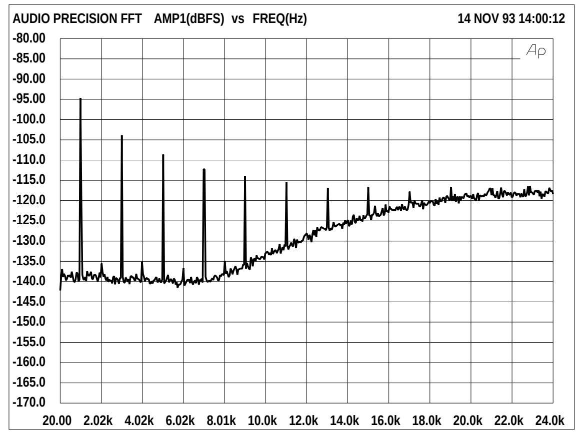

Fig. 10- 16 bit input signal -100 dB
Acoustic Bit Correction applied

Figure 9 shows the original 16 bit input signal processed with high-pass dither only. Notice that the additional distortion is gone.

Figure 10 shows Acoustic Bit Correction (dither and noise-shaping) applied to the same signal with an increase in the effective noise floor. Acoustic Bit Correction cannot remove truncation distortion in an incoming 16 bit signal, but it can avoid additional truncation distortion if additional processing, such as sample rate conversion, has been applied.

Noise-Shaping Curves

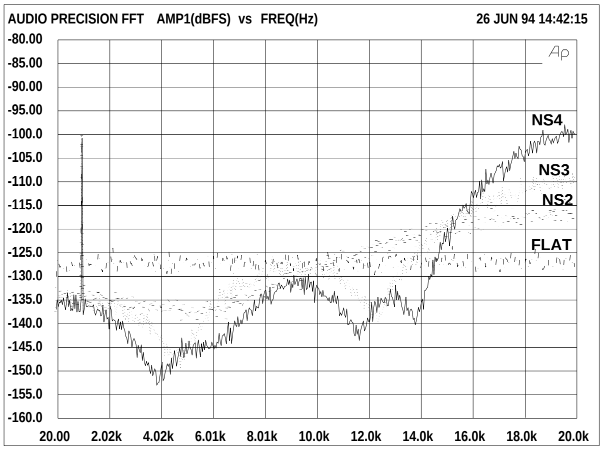

Fig. 11- 1kHz input signal -100 dB
Flat dither, with multiple noise-shapers shown

Figure 11 compares Flat dither with NS2, NS3, and NS4 noise-shaping curves. Note the increasing aggressiveness of the curves, with the pronounced dip at 4kHz and in the 12kHz region. These correspond to the most sensitive areas of the ear to noise.

Quantization noise is shifted from these areas to high frequencies, where the ear is less sensitive. Noise-shaping curves should be selected based upon listening tests of specific material to be dithered.

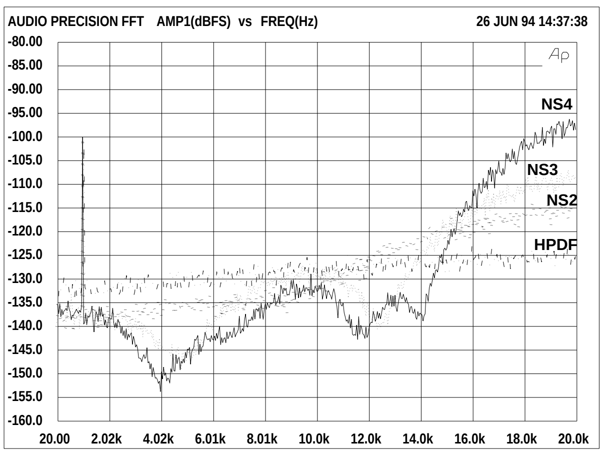

Fig. 12- 1kHz input signal -100 dB
HPDF dither, with multiple noise-shapers shown

Figure 12 compares High Pass dither with NS2, NS3, and NS4 noise-shaping curves. High Pass dither gives more noise shaping in the high-frequency band, while slightly lowering low frequency quantization.

Note: in Figures 11 and 12, the NS1 curve has been omitted for clarity. It lies below NS2 in both cases.