An Analysis and Comparison of Bit Depth and Sampling on an Early Recording

For early recordings, or those now in poor condition due to surface noise and other artifacts, the effective bit depth is determined by the characteristics of the material, the intrinsic noise level and the signal amplitude. Similarly the bandwidth is affected by the early recording process which was restricted to less than a few KHz.

We have used one of the 1890 Jesse Fewkes wax cylinders (#4235) to study bit depth and sampling, and compare a stylus transfer (using the Archeophone) with a 3D IRENE optical transfer.

The figure below on the right compares the frequency spectrum as measured from the Archeophone transfer (blue curve) and the 3D IRENE transfer (orange curve). Most of the audio content is between 200 and 4000 Hz. Typically the acoustic recording systems had poor response below a few hundred Hz due to the nature of the recording horns. The acoustic systems could also not capture audio above a few KHz due to the nature of the recording diaphragms. The striking features of the plot are the large differences between the Archeophone and IRENE 3D transfers below 100 Hz and above 3000 Hz, and the broad peak seen at 24 KHz in both.

The very low frequency audio content is not a recorded sound but rather a playback distortion ("rumble") due to the uneven rotation of the cylinder. IRENE 3D is not programmed to reproduce "rumble" or any other dynamic effects because these are typically considered deleterious to the listening experience.

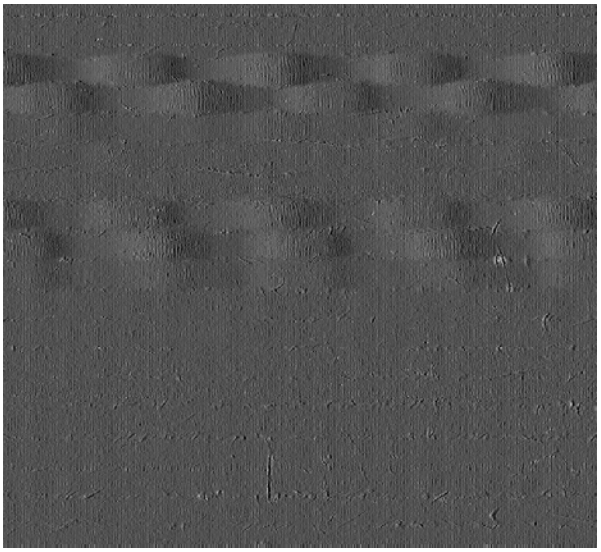
The second figure indicates that the size of the playback stylus determines how accurately high frequencies will be reproduced. For the Archeophone playback the stylus is chosen to seat properly in the groove and therefore determined by the groove width. The dramatic roll-off above 3000 Hz is a "tracing error (distortion)" since the Archeophone cannot follow the smallest undulations of the groove correctly once the stylus diameter is greater than or equal to the surface wavelength. For the IRENE 3D, the effective stylus size is much less. Such a tracing error would only start to occur above about 100 KHz. Decreasing the Archeophone stylus would lead to distortion and excessive pressure on the wax.

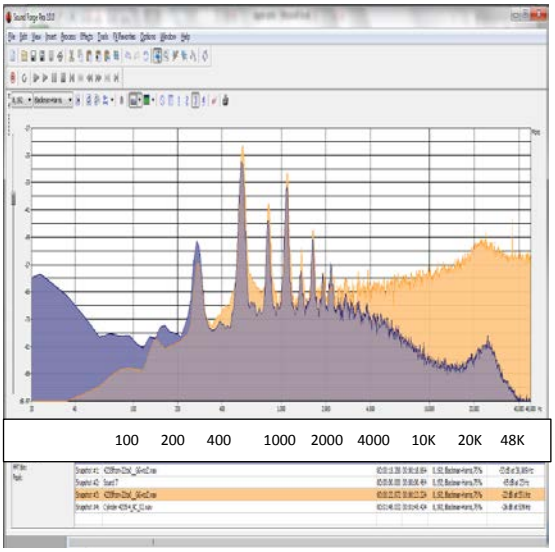
Referring to the upper figure at left, there is a fine surface texture on the Fewkes cylinder which is visible to the eye in the image provided by the IRENE 3D capture. That texture corresponds to a frequency of 24 KHz, well above our hearing range and well above what the acoustic diaphragm of the cylinder recorder could have captured. It may have been caused by a mechanical vibration during the recording process but is clearly present in the image and both playback systems.

IRENE 3D is not limited in the frequencies which can be captured as demonstrated by the data presented. This is a clear and substantive advantage of the optical method for the purpose of preservation. The IRENE 3D data is captured at 96 KHz and is flat in response. The Archeophone data was captured by a digitizer running at 96 KHz but the stylus response to the surface limits the transfer, effectively to about a 10 KHz sample rate.

For both of these transfers the effective bit depth is similar and determined by the characteristics of the recording itself. In this case the bit depth is also determined by the noise level. If one restricts the IRENE 3D data to the same bandwidth as the Archeophone data, this results in an effective bit depth of 7 bits (peak level) and 4 bits (RMS), for both methods.

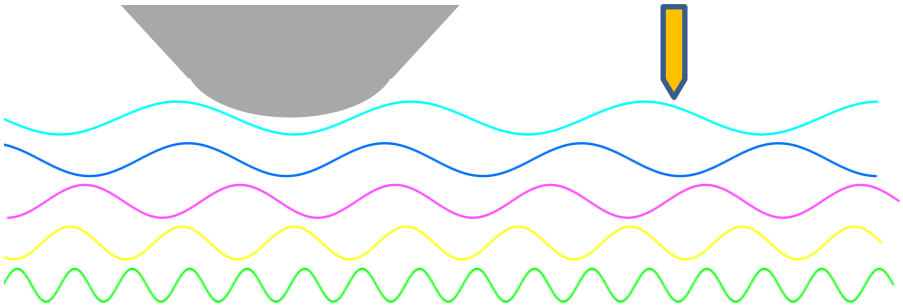
A Stylus/Optical Comparison





Left figure is a high resolution optical scan of a portion of the Fewkes cylinder #4235. The time direction is left-to-right. The horizontal bands are the groove. Though subtle a high frequency texture is visible which corresponds to the 24 KHz feature observed in the audio playback.

Right figure is a comparison the frequency spectrum of the Archeophone transfer (blue) and the IRENE-3D transfer orange. This is discussed further in the text.



This figure describes qualitatively the difference between and Archeophone/stylus transfer and an IRENE/optical transfer. The five sinusoidal waveforms represent the surface of the wax cylinder. Left to to right is the direction of time. The top curve represents a recorded tone of a few KHz and the lower ones of increasing frequency. The physical size of the Archeophone stylus is indicated by the grey object at upper left. As the frequency increases its ability to trace the full grove profile is attenuated. The orange shape at upper right represents the optical probe which has a spot size so small as to be able to trace a profile in excess of about 100 KHz. It is not practical to make a mechanical stylus much smaller than shown because it would not fit properly across the groove, leading to more distortion, and the local pressure on the wax would increase.