

# Digital simulation of phonograph tracking distortion

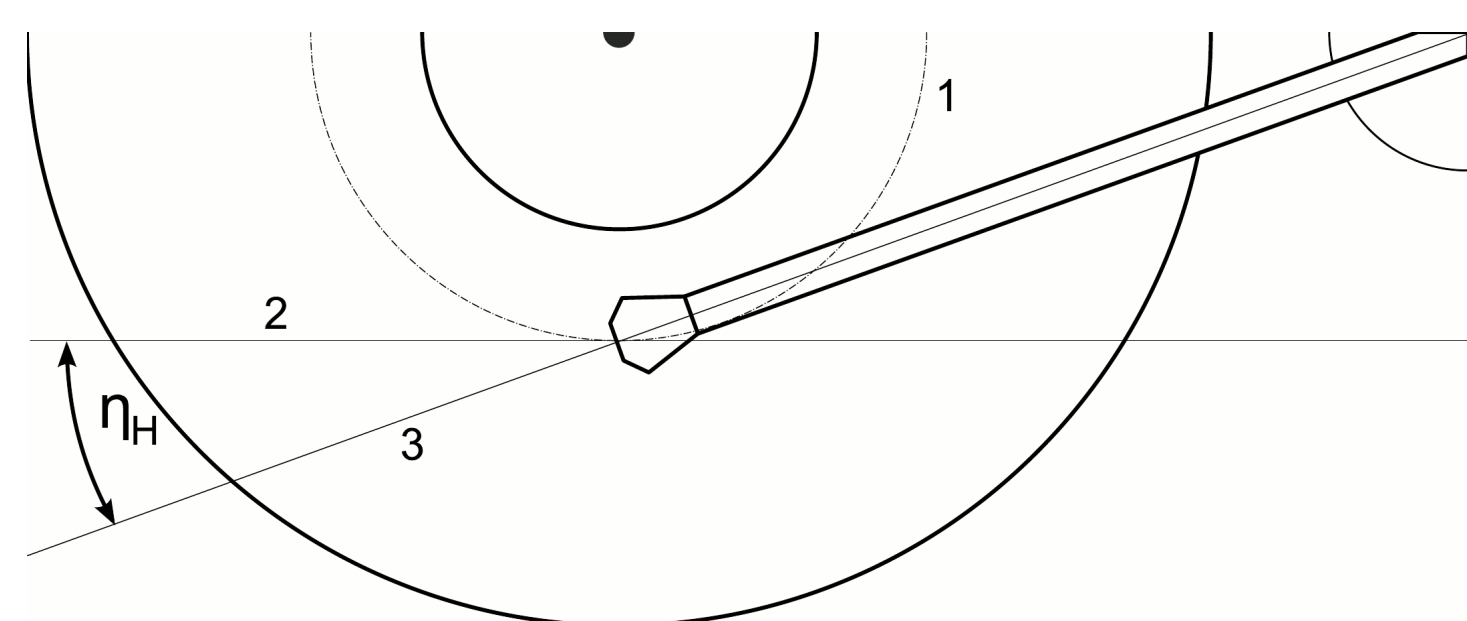


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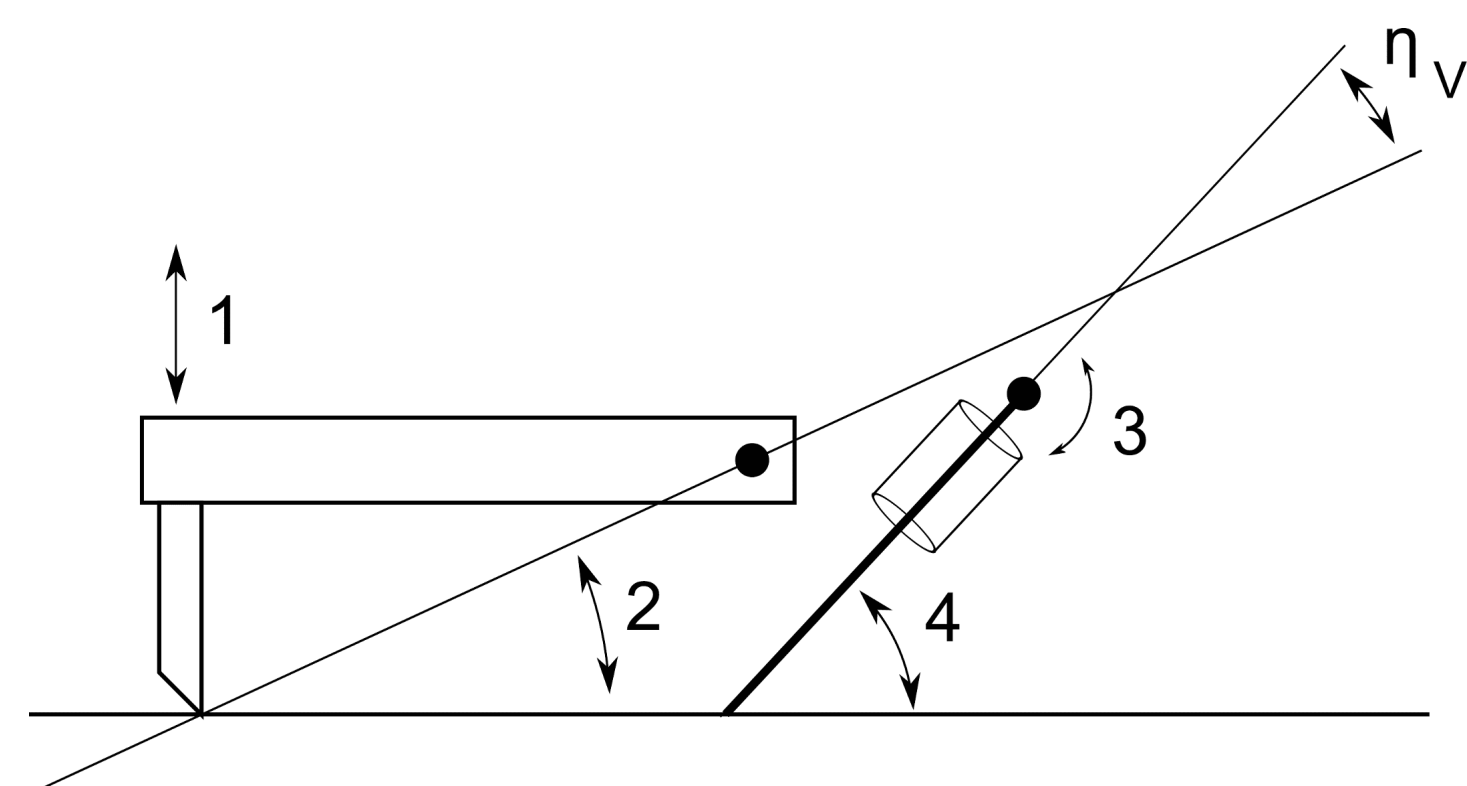
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When misalignment occurs in the playback of vinyl records, a characteristic distortion known as tracking distortion occurs. Its analysis is exact for sines and sums of sines but more intractable for aperiodic signals (music). Here, the modeling of the physical system in the pulse code modulation (PCM) domain allows its simulation to arbitrarily high accuracy, with no signal restrictions.

**Tracking distortion occurs when the playback cantilever of a record player is misaligned with respect to the cutting head.**



Horizontal tracking distortion (cantilever misaligned with record groove)



Vertical tracking distortion (angle from cantilever to record surface differs from angle of cutting head to record surface)

## Why does tracking distortion matter?

Tracking distortion is universally despised by audiophiles and digital audio partisans alike. Its minimization is the primary justification for such products as album pressings in 12" 45rpm, extended-length and linear tonearms, tonearm height adjustments, proprietary cartridge alignment systems, etc. - not to mention countless hours spent realigning record cartridges to exacting standards! Even so, it cannot be eliminated entirely.

No truly accurate simulation of tracking distortion is available, and it cannot be isolated from other sources of distortion in a physical phonograph implementation. Thus, the "sound" of tracking distortion, in isolation, remains a mystery. Contemporary estimates of its importance vary by several orders of magnitude.

## Idea: Simulate tracking distortion as pure jitter, applied to PCM signals

Tracking angle error causes crosstalk between a *signal* axis (the axis of modulation) and a *time* axis (the rotation of the groove). The signal magnitude modulates the time value associated with that signal by a proportional amount. This is, essentially, a form of phase modulation. If digitized, it could also be treated as a form of sampling jitter.

Sampling jitter can be accurately simulated through a method similar to that previously used by Hawksford, by displacing the original PCM samples by fractional delays, in proportion to the sample value, and interpolating between the displaced samples to obtain a uniformly sampled output. (Note that, in comparison, samples in a digital audio jitter simulation are typically displaced in a manner uncorrelated to the input.)

## Simulation Accuracy

- Ratio of second harmonic to fundamental for one specific simulated playback configuration: Simulated=1.219%; Predicted=1.2221%
- Simulated output nulled against predicted output: peak level -117dbFS, no spectrum component above -120dbFS; only six components above -144dbFS

## Possible uses

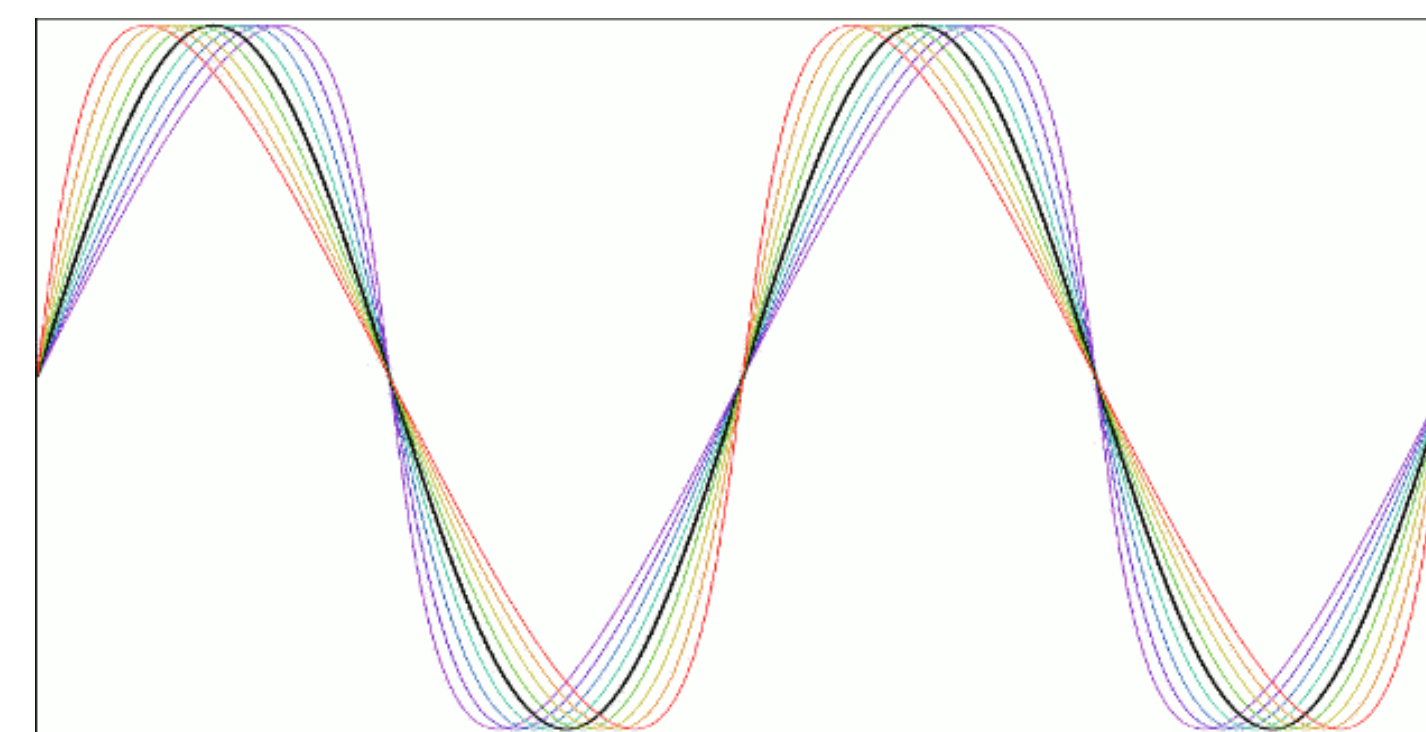
- Comparison of tracking distortion in isolation vs. reference
- Run controlled listening test to establish audibility thresholds
- Distortion cancellation: Estimate the tracking distortion in a recording, run through simulator with negative distortion - output should be less distorted
- Extend to simulation of tracing distortion
- Antiquing and music production
- Improved tracing/tracking simulation devices for record mastering

## Limitations

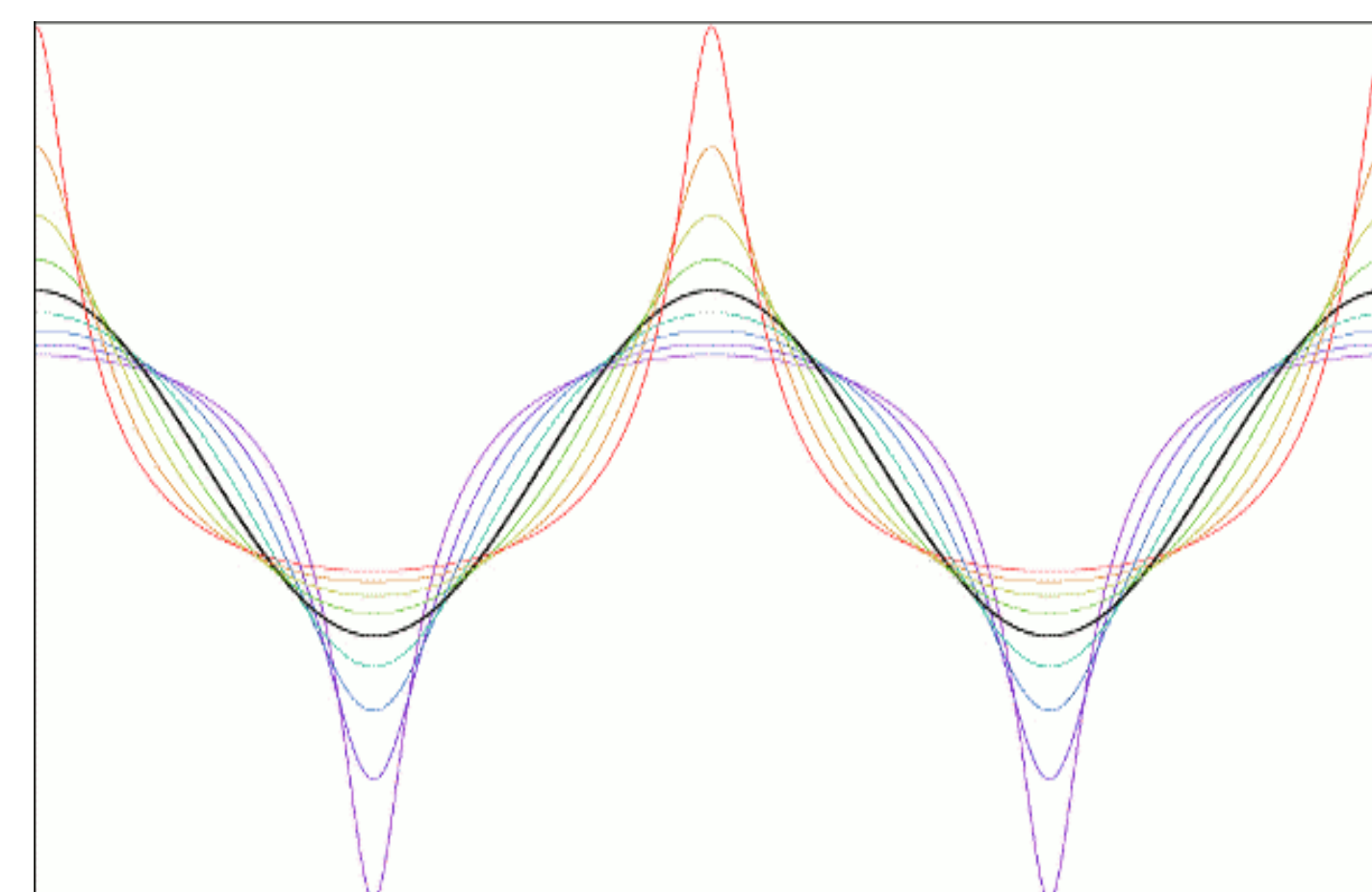
Tracing distortion interacts closely with, and may be more audible than tracking distortion. Interactions may increase the sensitivity of tracking angle errors beyond what is estimated from an evaluation of tracking distortion alone.

Extensions of this simulation for tracing distortion are inherently limited. An accurate simulation of, for instance, stylus rake angle (SRA) may preclude this simulation method from being used.

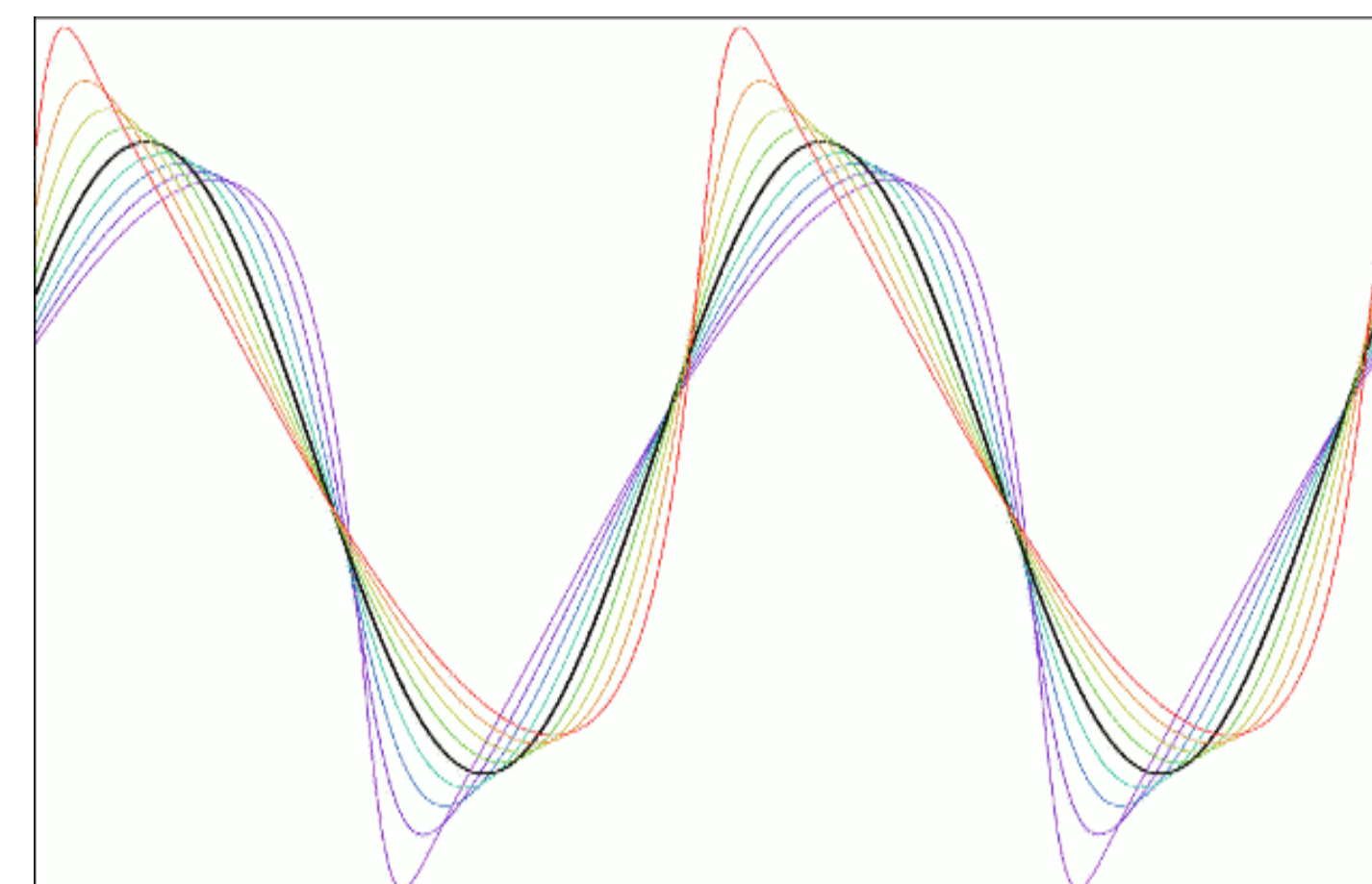
## Simulated output plots



A sine wave affected by positive and negative levels of tracking distortion: signal positions are moved forwards and backwards in time, proportional to signal values. This represents the distorted motion of the cantilever tracking a modulated groove.



Above, with numeric derivative applied. This represents the velocity-sensitive electrical output of the magnetic cartridge. Note how the peak-to-average value increases with increasing levels of distortion.



Above, with RIAA filter applied. This represents the final audio signal which leaves the phono stage.

## A preliminary listening test

Objective: Establish loose upper bounds for audibility thresholds for tracking distortion as a benchmark for future study. The author and a separate listener tested to the best of their abilities, one sighted, one blind. Sample signals are from EBU SQAM.

Results: Gross amounts of vertical tracking error (over 15 degrees) affirmed to be audible. Both listeners' results were subjectively very similar, despite vast protocol differences. Audibility thresholds seem remarkably consistent with a subjective description (by Cooper) of audibility of tracking distortion from the 1960s.

Nevertheless, an authoritative test may lower these audibility thresholds by substantial amounts, and is in the planning stages.

## Of what use is an audibility threshold?

- Affirms required accuracy levels for best cartridge alignment. Depending on the threshold found, this may result in either increased attention paid to alignment (and higher sound quality), or more relaxed alignment requirements (lowering the time investment necessary to get the same sound quality).
- Suggests maximum allowable vertical tracking error for inaudible levels of distortion.
- Evaluates the audible level of distortion resulting from the use of a 9" tonearm compared to a longer or linear arm; suggests a minimum acceptable tonearm length for optimal sound quality.

## Jitter versus Tracking Distortion

Tracking distortion is purely a time modulation, just like jitter. That is, to say that vinyl is completely free from temporal distortions, in the way that digital audio is not, is false. However, the unique relationship between tracking distortion and the signal input may not exist in digital audio systems; the two distortions are clearly not the same thing.

## Future work

- The tracking distortion simulator will be released "soon". Sources will likely be made available.
- The importance of tracing distortion for evaluating tracking distortion will be further studied.
- A listening test will be organized to obtain more rigorous audibility thresholds for tracking distortion.