MORE THAN ONE VERTICAL TRACKING ANGLE

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Discwasher Laboratories has recently been investigating high-performance phonograph playback, and as a result of our investigations, we have become aware of several unusual aspects of the vinyl playback system (VPS). In one of our studies, we were concerned with the microscopically small dimensions involved where the record groove is being dragged past the playback stylus, as well as more visible aspects such as vertical tracking angle (VTA). In our tests, we wished to retrieve as much undistorted information as possible, and among the VPS parameters we felt should be optimized was VTA. Correct VTA for the VPS, in classical theory, involves having the playback angle match the cutting angle (Fig. 1). Physically, VTA is the angle between the surface of the record and the line described by the contact point of the stylus in the groove and the pivot point of the cantilever. This relationship is analogous to and originates in the recording process. The theoretical importance of matching VTAs between recording and playback has been widely expounded, and popular explanations of causes and effects are generally available, but they should be examined in some detail to fully understand their consequences. Mismatch of playback VTA to the recorded VTA is said to cause one minor effect: Frequency modulation of the highs present in program material in response to any significant level of low-frequency vertical groove motion. Referring to Fig. 1 again, notice that the vertical-modulation arc

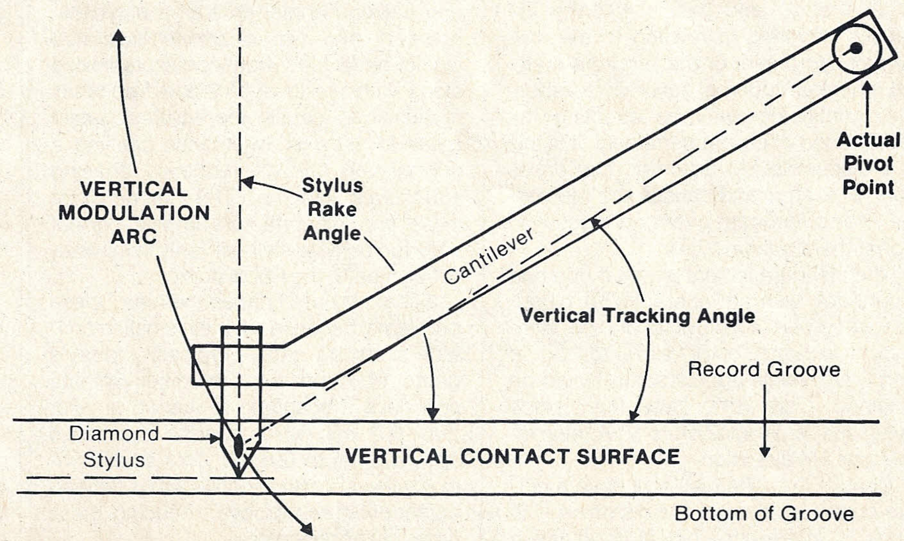

Fig. 1 — The playback system, showing the relationships of vertical tracking angle (VTA), stylus rake angle (SRA), and vertical modulation arc; side view through groove.

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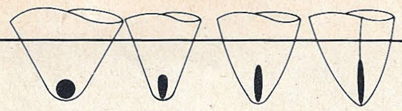


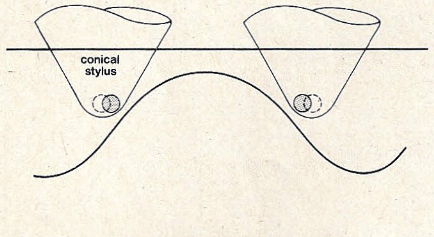
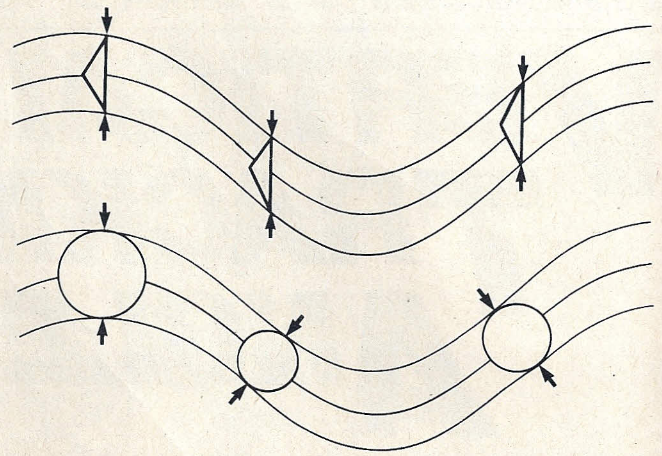


Fig. 2 — Conical stylus tracing error with vertical groove modulation, showing contact patch or footprint shift from reference position; side view through groove.

Fig. 3 — Conical stylus tracing error with lateral groove modulation, showing contact point (center of contact patch) skew relative to cutting stylus; top view.



shown is characteristic of any vertical (out-of-phase) modulation in the groove. Because of this arc and the resultant forward and backward motion along the groove, the momentary linear cutting speed would be varied proportionally to the amount of horizontal displacement this vertical motion causes. Any time this occurs, any frequencies higher than the dominant vertical-displacement low frequency will be modulated by that low-frequency displacement. Of course, all this is not a problem if the recorded VTA is replicated in playback, whereby the frequency modulation (FM) is cancelled due to the vertical-modulation arc being the same. The sonic effects of a VTA error are similar to flutter, heard as wavering of the high frequencies. There is an important difference between typical flutter and frequency modulation due to VTA error, and this is that the FM causes wavering in relation to the low-frequency content of the program material whereas flutter is generally a repetitive, continuing variance affecting the entire range of program material. It is this time-dispersive FM distortion that arises from VTA error and causes the theoretical furor of concern over cartridges with higher than optimal VTAs.

The literature indicates that if one had a cartridge with an inherent VTA higher than recorded angle, it could be tilted back (cartridge body allowing, some won't) and minimum distortion would be obtained. This isn't quite true, since stylus shape, in addition to VTA, also influences FM distortion.

Conical (or spherical) styli have a certain built-in amount of FM distortion with *either* a lateral or vertical modulation (Figs. 2 and 3). As shown in Fig. 2, due to the ultimate rounded tip shape of the conical stylus, a significant vertical modulation will cause the contact patch to shift. From the center or reference position, a stylus drift or lateral thrust ahead and then behind will cause exactly the same type of distortion as VTA error. Both are slope related and can augment or tend to cancel depending on the sign (polarity) of the VTA error. The amount of FM due to the stylus shape will vary in relation to the stylus radius and the amplitude of the vertical modulation.

With lateral modulation (Fig. 3), the FM inherent to conical styli occurs on both channels in opposite directions, so the mono (sum) signal would show little or no FM effect (depending on the accuracy of lateral tracking angle). In stereo playback, however, the two channels illustrated would have high frequencies recorded along with the lows. The low-frequency modulations cause the stylus contact areas to skew or twist, thus causing a degradation of high-frequency phasing and stereo imaging. The net result of these and other factors is that correct VTA for conical styli will only minimize, not eliminate, the FM distortions.

Other stylus shapes reduce these problems because of their smaller contact scanning radii. Typically, today's genre of elliptical or modified-Shibata styli have a scanning radius no smaller than 0.2 mil, while conical styli range from 0.5 mil to 0.8 mil. This smaller radius allows a more consistently defined contact with the groove, reducing these types of FM distortion.

Our tests indicated elliptical and Shibata-type styli have another parameter of dramatic importance not present with conical styli. This overlooked factor is called stylus rake angle or SRA, which is the angle that the vertical center line of the stylus contact patches make with the groove modulation ridges. Stylus contact areas for different types of styli are shown as black vertical patches at the bottom of Fig. 4. As seen in this figure, the Shibata-type stylus shows the longest, narrowest contact, while the conical stylus predictably has a circular contact patch or footprint. The elliptical and modified elliptical stylus shapes fall in between these extremes. Due to its long, narrow footprint, the Shibata-type stylus is theoretically very sensitive to positional changes in SRA. Any misalignment of the footprint relative to the groove modulation ridges will cause its vertical footprint span to increase, resulting in possible losses of very high frequency modulation (scanning loss).

Our detailed models showed that this increase in the effective scanning radius does not result in a simple, smooth, effective broadening of the stylus footprint. Due to the nature of the tilted, narrow contact edge, the manner in which this edge contacts the groove modulations is somewhat nonlinear and more complex as compared to a simple conical stylus shape of comparable radii. Physical modeling showed the tracing errors which arise with a misaligned Shibata-type stylus are similar to, but greater in distortion level than those of a conical stylus, and similarly result in some low-frequency-dependent FM of the decoded high frequencies.

We therefore hypothesized serious geometric potential for improper SRA of Shibata-type styli. The groove modulations can grab at the scanning edges of the stylus, torquing or attempting to twist the stylus which can send vibrational shocks up the cantilever.

From the modeling of these factors, it would seem both VTA and SRA should be corrected for optimal playback. Yet the physical connection of cantilever and stylus causes both of these parameters to vary simultaneously. There is a fixed relationship between the inherent VTA of the cartridge, when set up as recommended, and the SRA which results from the fixed stylus chip vs. cantilever attachment.

When considering the proper vertical alignment of our test system, we had to decide whether we should align for correct VTA, proper SRA, or some optimal compromise position so as to maximize undistorted information retrieval. Before we could make that decision, we decided to assess the effect of varying VTA. Our test system consists of a Denon direct-drive DP-80 turntable with a modified DA-401 tonearm with the ability of in-play rear-pivot-height adjustment via a precision micrometer. Several different moving-coil cartridges were used in tests with an HA-1000 pre-preamp running into a modified lab reference preamp. The output of this preamp was observed via a Tektronix 466A Storage Oscilloscope and/or with a GenRad 2512 Spectrum Analyzer. Test data could be plotted on an Easterline-Angus 575 X-Y plotter for reference plots, etc.

Some initial tests were conducted consisting of spectrum analysis of vertical modulation IM bands (CBS STR-112 test record) where the vertical angle was varied using a moving-coil cartridge having a modified elliptical stylus. The results of these were somewhat inconclusive as there seemed to be no clear-cut indication of a minimum level of distortion at the various angles of playback. There were some subtle and generally inconsistent shifts in the distortion spectra with changes in VTA, although their significance was not determined until some time later.

In order to control the variables in our test system, cartridge tests were performed using the DIN 45-542 VTA test record [1], which has bands with varying

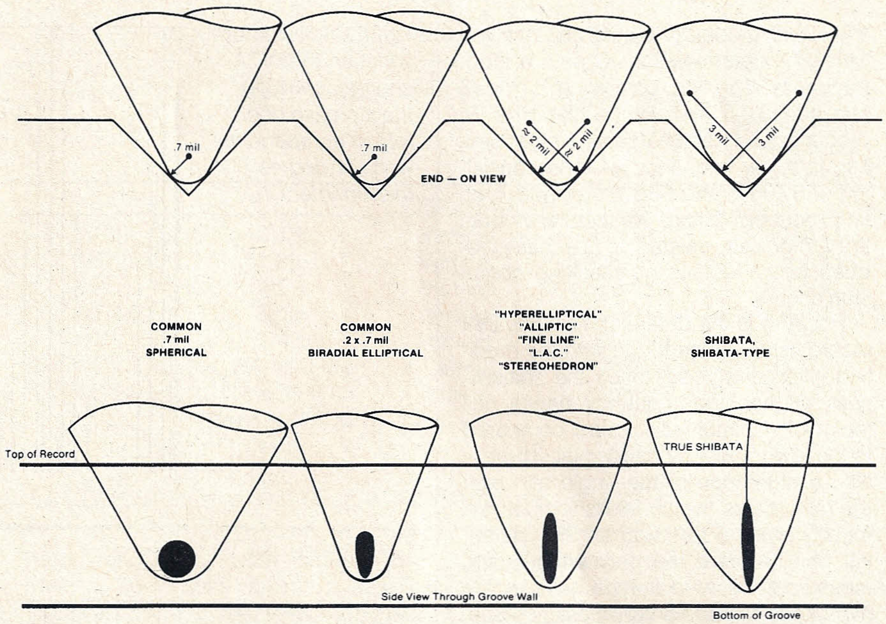
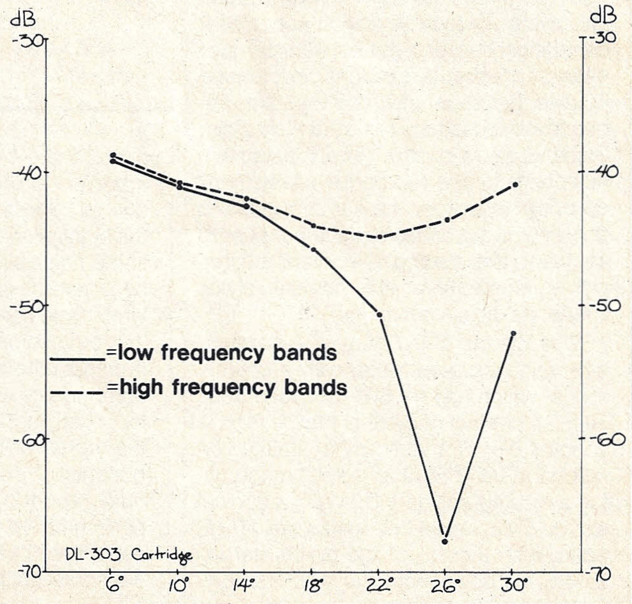


Fig. 4 — Groove contact geometry of four common stylus shapes.

Top: End-on view or profile as stylus rests in groove with no sink-in shown.

Bottom: Side view through groove with black patches showing stylus footprint or contact area.

Fig. 5 — An IM distortion vs. VTA variation comparison, showing null points in the high and low frequency sections.



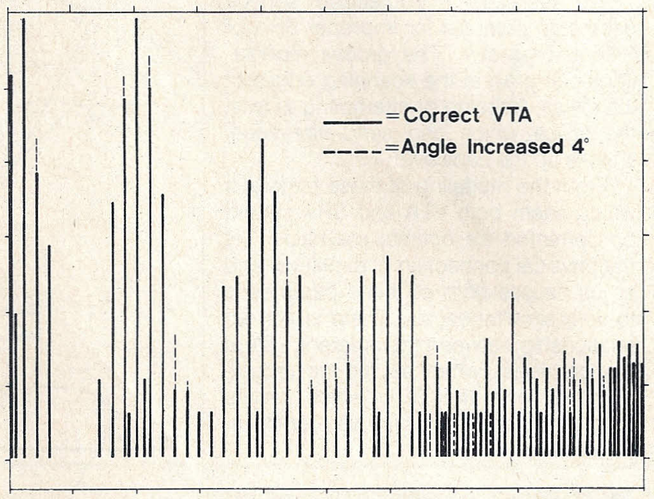


Fig. 6 — Distortion variation with VTA change, showing the increase of distortion components with a 4-degree misalignment in VTA.

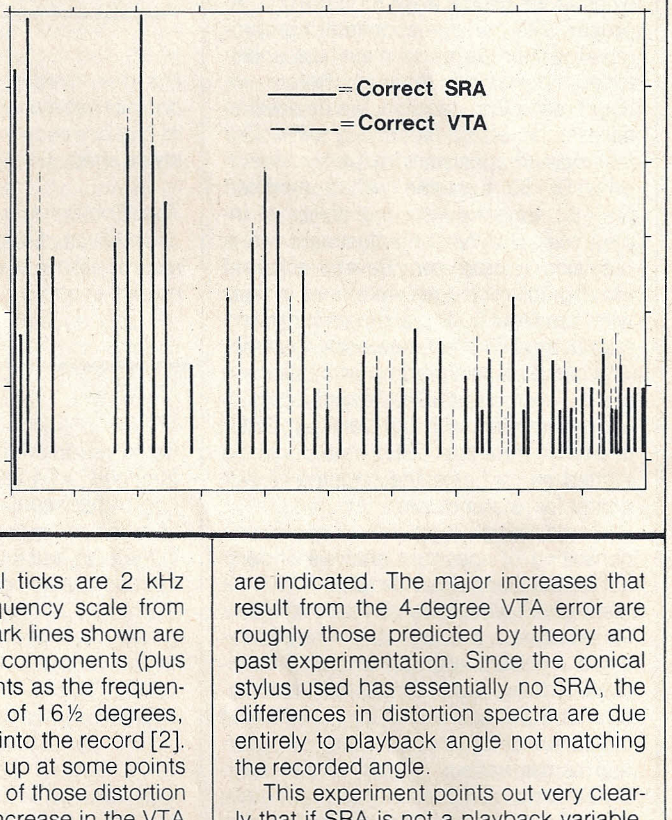


Fig. 7 — SRA vs. VTA (or record/playback angle match), showing the increase in distortion with misaligned SRA, even though the record/playback VTA is matched.

VTA. Two groups of bands are involved with VTA determination: One is a high-frequency IM tone consisting of 1.85 kHz and 3.15 kHz with a high-side IM product of 5 kHz, whereas the other section is a low-frequency IM tone consisting of 370 Hz and 630 Hz giving a high IM product of 1 kHz. Neither IM product is harmonically related to the base frequencies, and thus no masking confusion occurs.

Figure 5 is the data plot from this DIN record using the cartridge with the modified elliptical stylus. Notice the shallowness of the high-frequency bands null (point of minimum distortion) compared to the low-frequency bands null. There is also a difference in the angle at which the null occurs, which tends to hold true for any stylus shape with an SRA potential. If VTA were the only effect being measured, the IM distortion nulls for the two bands should be very close in slope, shape, and location. We theorized that the observed difference in the nulls (Fig. 5) was due to SRA interaction with the shorter wavelengths involved in the high-frequency section of the tests. The shallowness of the high-frequency null is most likely a result of the different SRA-to-VTA relationships between the cutting system and playback cartridge (about 25 degrees difference in this cartridge). We feel it was a similar effect in the initial VTA tests that caused the spectral plot of distortion products to show little overall change on the CBS test record.

Tests with a cartridge having a conical stylus always gave a much closer correlation between the nulls for the two different frequency sections and tended to give a deeper null for the high-frequency bands than for other (elliptical, Shibata) types of styli. The reason that null points for the two frequency sections do not give exactly the same angle and depth was hypothesized to be due to some of the tracing distortion mechanisms inherent in the conical stylus shape, as discussed earlier.

One means of isolating VTA parameters is to use a cartridge with a conical stylus, which has no SRA because of its circular contact footprint. Figure 6 is a spectral plot of a vertically modulated IM test band (400 Hz and 4 kHz) made using a moving-coil cartridge with a conical stylus. The vertical tick marks are 10 dB apart, with the top of the graph starting at -25 dB down from the 400-Hz component; the horizontal ticks are 2 kHz apart on a linear frequency scale from d.c. to 20 kHz. The dark lines shown are the original distortion components (plus some noise components as the frequency goes up) at a VTA of 16½ degrees, which is the angle cut into the record [2]. The dotted lines rising up at some points represent the increase of those distortion components with an increase in the VTA by 4 degrees to 20½ degrees. Notice the increases in the second-order components of about 5 dB, consistent with data reported by others [3] who have performed tests with conical styli. There are a few other locations where the levels come up a bit, but no major trends are indicated. The major increases that result from the 4-degree VTA error are roughly those predicted by theory and past experimentation. Since the conical stylus used has essentially no SRA, the differences in distortion spectra are due entirely to playback angle not matching the recorded angle.

This experiment points out very clearly that if SRA is not a playback variable, proper matching of record and playback VTA results in lowest playback distortion. It must be kept in mind that the increase in the second harmonic of 400 Hz is due to slope-related waveform distortion, while the increase of the 4-kHz component sideband is due primarily to increased frequency modulation of 4 kHz — a more objectionable form of distortion than harmonic distortion.

The next step was to test for distortion differences between the optimization of VTA for proper SRA alignment or for vertical-modulation arc matching. At this stage of our experimentation, we attempted some tests using a Shibata-type stylus with a bent cantilever tube to give odd combinations of SRA-to-vertical modulation arc alignment. We were never able to make a satisfactorily "clean" bend due to the Shibata-type configuration and its need for critical vertical (head-on) alignment, but the data produced were intriguing.

We were, however, fortunate to have in our stock of cartridges a unit deemed defective due to a stylus misalignment. This cartridge had a modified-Shibata stylus which was slanted more than a typical unit. When properly aligned for SRA, this cartridge was slightly more than 4 degrees "low" in proper VTA match. Figure 7 illustrates the results of the correct SRA versus correct VTA experiment, with the same basic data display as Fig. 6. A distinct distortion increase is shown when SRA is misaligned and the correct VTA match is also made. Compare Figs. 6 and 7, and it will be seen that for an equal degree of misalignment, the SRA parameter is most significant in causing a rise in distortion, especially higher order distortion products. Notice, too, that when the modified Shibata stylus is correctly aligned for SRA, distortion products are at lower levels than when VTA is correctly aligned for the conical stylus. These data are fairly conclusive regarding which parameter is of importance for different styli.

Reported listening tests concerning VTA alignment have said that as little as 1/30 of a degree can make an audible difference in the clarity of the music, with a higher than optimal misalignment causing excess brightness. These reports typically do not distinguish between VTA and SRA even when the report mentions the existence of SRA. The results of our tests indicate that the parameter being optimized in these reports was almost undoubtedly SRA. Our own informal listening tests bear this out as well. When SRA is correctly aligned the sound quality "locks-in" and the retrieval of minute details is enhanced.

Table I — Frequency modulation data for different conditions.

VTA (±½°)	Freq. Deviation at 4 kHz	Modulation	Stylus Type	Sum of 2nd-Order Sideband (Major Distortion Level)
14°	2.1%	Vertical	Conical	12.0%
16½°	1.8%	Vertical	Conical	11.1%
19°	2.2%	Vertical	Conical	12.8%
21½°	2.5%	Vertical	Conical	16.4%
≈14°	1.4%	Vertical[1]	Shibata	—
14°	L 1%, R 0.6%	Lateral	Shibata	—
16½°	L 1.3%, R 0.8% Mono 0.0% for both	Lateral	Conical	—

[1]CBS STR 112 test record, Band 7, Side B (400 Hz and 4 kHz).

These conclusions were further confirmed by some tests utilizing a laterally modulated 500-Hz asymmetrical square wave cut from Denon test record XG-7003. This recorded signal has a series of finely detailed harmonics extending above 40 kHz. We postulated that a misalignment of the stylus would alter or lose the harmonics. When a 4-degree tilt to the optimal SRA was introduced, alteration of the harmonics as low as 5 kHz and 7 kHz occurred and losses of harmonics above 30 kHz were evident! These changes are subtle, but at the same time consistent and repeatable.

We studied the frequency deviation for the 4-kHz component of the IM tone used throughout these tests. An experimental comparator based on a PLL IC was used for these tests. While absolute accuracy may not hold, the relative rankings remain accurate. Table I lists the results of these measurements taken under various conditions of VTA. It can be seen from these figures that there is an alarming amount of distortion present, although in practice vertical modulation tends to be rare in recording. In fact, the thickness of the recording lacquer, commercial considerations, and engineering expertise generally keep vertical cutting low, and thus phase information coherent.

Our calculations indicate that maximum cantilever vertical-arc travel is typically 1 degree due to these limitations. Another theoretical aspect of VTA match often overlooked is cantilever length, which should be matched between cutting and playback systems. There is no standard for these lengths, and cartridges we have examined show gross differences in cantilever length and do not correlate to cutting systems.

Thus, our investigations clearly show SRA to be a more important controllable variable than VTA. Our dialogue with cutting engineers indicates that VTA currently varies between 16 and 22 degrees, depending on the lathe system. SRA, however, is generally 91 to 95 degrees relative to the record surface in order to facilitate lacquer "chip" (cutaway strand) removal.

Proper hi-fi set-up should therefore concentrate on cartridge adjustment that has the tip of the stylus pointed "back" toward the tonearm pivot, and the top of the stylus tipped "forward" so that the contact SRA face is 92 degrees between the stylus and the record surface. Such alignment will at least approximate correct SRA. (One cautionary note: True Shibata styli do not have their stylus contact area or footprint lined up with the bulk of the stylus chip, and this should be taken into account when adjusting for proper SRA.) The effects are clearly audible on a fine audio system. A

References

1. Available from Gotham Audio Corp., 741 Washington St., New York, N.Y. 10014.
2. White, James V. and Arthur J. Gust, "Three FM Methods for Measuring Tracking Angles of Phono Pickups," *Jour. of the Audio Eng. Soc.*, Vol. 27, No. 4, April, 1979, p. 242.
3. Halter, Jerome B. and J.G. Woodward, "Vertical Tracking Angle Errors in Stereodisk Systems," *Jour. of the Audio Eng. Soc.*, Vol. 12, No. 1, Jan., 1964, p. 8.