

Introduction to Magnetic Tape Azimuth

Overview

This guide aims to clarify the role of azimuth in audio tape playback, a crucial but sometimes overlooked practice in preserving magnetic audio tapes. By delving into the principles and mechanics of aligning head and tape azimuth, it shall serve as a supplement to the comprehensive introduction presented in the ARSC Guide to Audio Preservation and a companion to Guidelines on the Production and Preservation of Digital Audio Objects: IASA TC-04. It also acknowledges the varied expertise within the international audiovisual preservation community and is intended to be an accessible reference for those with a basic understanding of magnetic tape principles and the broader significance of audiovisual preservation. Within these pages, readers will find an in-depth explanation of azimuth—its significance, principles, and the tools essential for achieving the highest quality audio playback and transfers. Special thanks are extended to Richard L. Hess and Nicholas Bergh for their invaluable contributions to this topic through numerous papers, presentations, and workshops. As we collectively navigate the complexities of audiovisual stewardship and preservation, the ARSC Technical Committee hopes this guide will serve as a key technical reference for cultural heritage stewards, audio engineers, collectors, enthusiasts, and other professionals engaged with audio media.

Audio production and preservation professionals recognize the significance of aligning playback with the technical characteristics of recorded tapes. These characteristics encompass track widths, speeds, equalization standards, and noise reduction encodings, all of which are critical for accurate tape playback. One often-overlooked element is the head azimuth, which denotes the angle between the head (specifically, the head “gap”) and a line perpendicular to tape travel (Figures 1 and 2.).

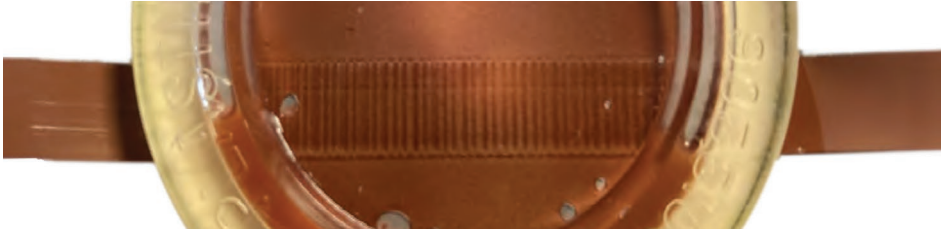


Figure 1. Full track tape visualized using a magnetic viewer.

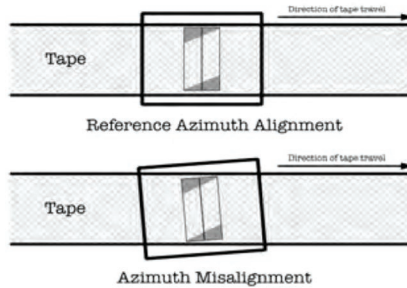


Figure 2. Diagram of tape head at theoretical “reference” azimuth and a “misaligned” azimuth.

But what happens when the gap in the reproducer head is not parallel to the recorded signal on the tape? One will experience azimuth angle errors, which can result in the following:

- Loss of entire frequency bands due to comb-filtering (Figure 3)
- Loss of high frequencies
- Distortions in the stereo image
- Additional noise
- Difficulty decoding noise reduction, if used

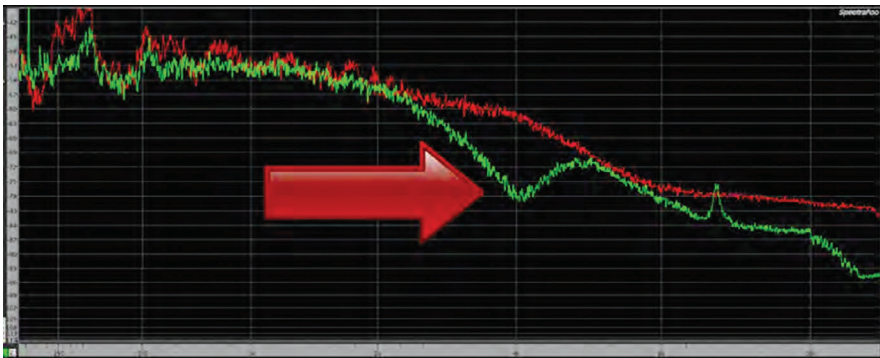


Figure 3. Example of destructive comb filtering in signal induced by azimuth angle error (green) compared with adjusted signal (red)

The severity of these problems depends not only on the degree of deviation between the reproducer head and orientation of the signal on tape but also by the tape speed and track width.

Reference azimuth versus program azimuth

Reference azimuth, also termed “zero” or “absolute” azimuth, represents the theoretical alignment of a head with tape travel at a precise 90 degrees. Due to the physical nature of magnetic tape and mechanical errors introduced during playback, perfect alignment is impossible. For example, imperfections in the tape manufacturing process (e.g., bad slitting or “country-laning”) can affect how the signal is recorded to and played back from a tape. The tape transport itself can generate mechanical errors stemming from wear in the guides and heads, differences in tape pack and reel table heights, and capstan/roller contact issues. Nevertheless, the standard procedure for servicing and calibrating machines involves using precise laboratory-made reference tapes to set head azimuth as close to perpendicular as possible. One can find many machine service manuals recommending this process for both record and playback heads when performing routine maintenance.

For recorded audio tapes, we can anticipate that the tape’s program azimuth will have some amount of deviation from the theoretical reference. For this reason, it is imperative to adjust the reproducer head azimuth according to the recorded content or program to ensure faithful playback, particularly for preservation. As a rule of thumb, azimuth errors will be more pronounced on tapes recorded with wider tracks and slower speeds. The following section will quantify the nature of azimuth errors in consumer and professional tape formats.

Quantifying azimuth errors

It can be helpful to think of program azimuth on a bell curve, where the best azimuth position is as close to its peak as possible (Figure 4). It is important to remember that azimuth adjustment sensitivity varies across recording configurations: the wider the track and the slower the tape speed, the more sensitive and critical it will be to dial in the angle of the playback head. In Figure 4, the bell curve with the steepest peak represents the narrow window for correct azimuth adjustment; this is typical for tapes with wide track formats such as full-track quarter-inch tape or slow speeds such as 1.875 inches per second (4.75 cm/second). In the subsequent bell curves, the window for correct azimuth adjustment becomes less critical for faster tape speeds and smaller track widths.

Due to their slow speed, cassette tapes (mono cassettes in particular) are very sensitive to azimuth errors. Certain tape formats stretch the limits of optimal sound quality, presenting a shape akin to a razor blade, making perfect azimuth calibration nearly impossible. Examples of such formats include slow-speed micro cassettes or 1.875 inches per second (4.75 cm/second) full-track quarter-inch tape, which demand greater precision for a successful transfer.

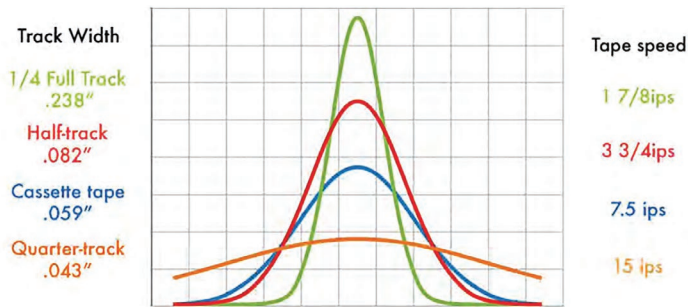


Figure 4. Illustration of the precision required for obtaining correct azimuth.

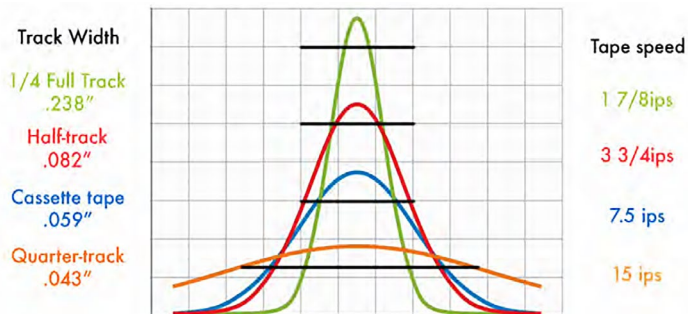


Figure 5. Approximations of thresholds for comb-filtering

Depending on how this bell shape looks for a particular speed and track width, a certain margin of azimuth error is tolerable before the program content starts to suffer. Initially, this manifests as a straightforward loss of higher frequencies.

However, if the deviation is excessive, comb filtering notches emerge, causing a severe and detrimental impact on the overall sound quality (Figures 3 and 5).

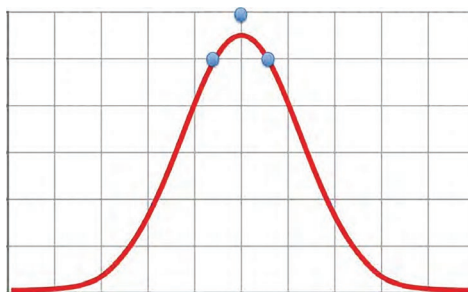


Figure 6. Bell curve with dots at the center and thresholds for margin of error.

While there is a degree of tolerance for azimuth precision, the objective is to pinpoint the center of the rounded peak, a task that can prove challenging. Mechanical factors during tape playback introduce complexities in locating the exact center, necessitating acceptance of an allowable range. As one approaches the center, there is increased room for azimuth drift in the tape. To navigate this somewhat ambiguous center point, a practical approach involves not attempting to discern the precise center through listening alone. Instead, one should identify equal high-frequency balance on both sides of the center point. Once this equilibrium is achieved, splitting the difference provides a close approximation to the center (Figure 6). This methodology helps achieve optimal azimuth alignment amid the inherent challenges of mechanical factors during tape playback.

Adjusting playback head azimuth

In cases where a recording was produced with a misaligned record head, it becomes necessary to intentionally misalign the reproducer head from zero azimuth to replicate the original azimuth position. In practice, the angle of misalignment is usually very small, and only minute changes in the head angle are required. Before making these changes, one needs to identify which screw and what tools are necessary to make adjustments.

The process of azimuth adjustment varies based on the tape format and the type of playback equipment used. For open reel tape machines, accessing the azimuth adjustment screw usually involves removing the head cover (Figure 7). It is important to note that the head cover plays a crucial role in minimizing electrical interference during playback. Therefore, practical scenarios may involve drilling a discreet hole to facilitate real-time azimuth adjustment with the cover in place. On most open reel machines, the azimuth screw can be adjusted using a hex key or screwdriver. See the table in the **Appendix** for specific sizes for models commonly used for preservation. Additionally, some open reel machines can be modified with dial azimuth controls with reference points indicating the range of motion (Figure 8). This modification proves beneficial for documenting the adjustment process, offering valuable preservation metadata information.

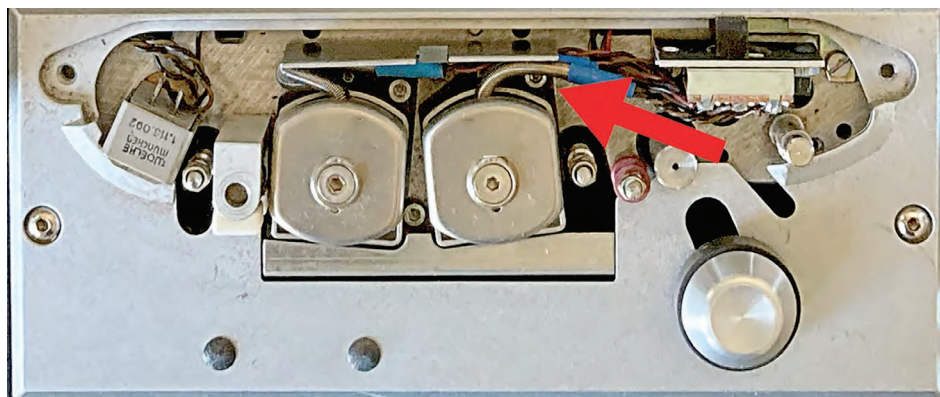


Figure 7. Location of azimuth reproducer head azimuth screw on Studer A810 with head cover removed.



Figure 8. Azimuth dial controls installed on a Studer A80 open reel quarter-inch machine

For cassette players, the azimuth screw can also be found near the playback head. Some machines have dedicated playback azimuth control dials. However, such configurations are relatively uncommon (Figure 9). Alternatively, some other machines facilitate easy access to the screw from outside the chassis through a small hole beneath the cassette door (Figure 10). In most cases, accessing the azimuth adjustment screw requires removing outer components. This screw is typically situated on one side, often the left side, of the playback/record head, structured in a screw and spring type arrangement (Figure 11).



Figure 9. Dedicated playback azimuth control on Nakamichi CR-7E



Figure 10. Example of Nakamichi 580 cassette deck with azimuth screw accessible from outside chassis



Figure 11. Closeup of azimuth screw in Tascam 122 MKIII with face plate removed

Azimuth adjustment principles

The fundamental process for aligning playback head azimuth to tape azimuth involves using auditory cues to locate the center and making incremental adjustments based on that feedback. For more critical work, assistive measurement tools such as oscilloscopes or real-time spectral analyzers can aid the process. When making changes, it is essential to monitor audio in the analog domain (pre-digital conversion) and on speakers or headphones capable of reproducing frequencies at least up to 20kHz, ideally in mono. For stereo or dual-mono material, it is recommended to sum the two channels to mono—blending the left and right channels equally—to better hear the effects of azimuth errors such as comb-filtering and high-frequency loss.

While auditioning the tape, one should adjust the azimuth screw for maximum high-frequency response. Using incremental left and right turns, oscillate the adjustment back and forth until the center becomes discernible, akin to manually focusing a camera lens (Figure 12-13). When making adjustments, take care to touch only the azimuth screw and to avoid over-tightening. The azimuth screw should never be fully tightened. Once the head is appropriately set, it is recommended to compare azimuth across the duration of the tape. As mentioned before, variations in the physical properties of the tape and drift introduced during recording can make it necessary to check for azimuth errors at

multiple points within a recording. Cassettes, in particular, are more prone to azimuth drift than reels; therefore, continuous monitoring is encouraged.



Figure 12. Making incremental turns to the left and right on a compact audio cassette player



Figure 13. Engineer making adjustments on an Ampex ATR-102

Metering and measurement tools

There are several metering and measurement tools that can assist with the adjustment process spanning from traditional hardware to complex software. A standard measurement tool used for tape machine calibration that can help illuminate azimuth errors is a dual-trace oscilloscope. As illustrated in Figure 14, the oscilloscope overlays the left and right channels, unveiling signal variations such as phase discrepancies.

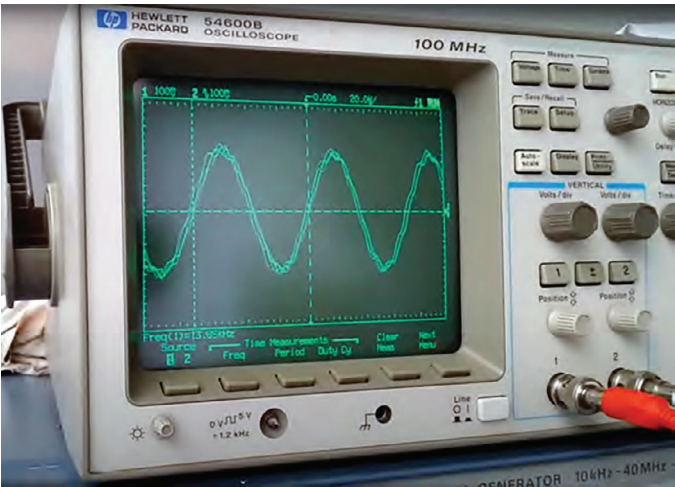


Figure 14. Measuring azimuth with an analog oscilloscope in dual-trace mode

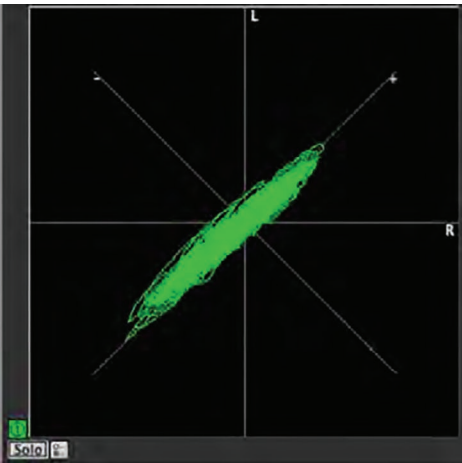


Figure 15. Examples of audio represented in an X-Y Lissajous curve.

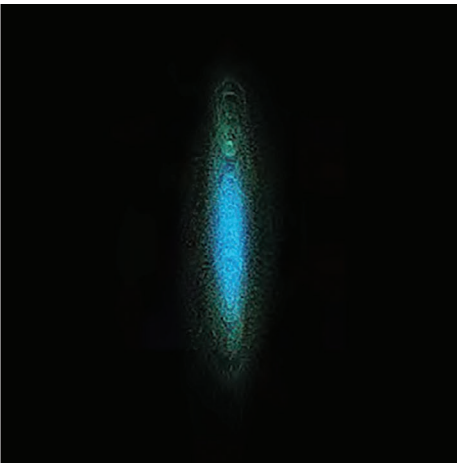


Figure 16. Lissajous as produced by FFMPEG's avectoscope command.

In the digital domain, digital audio workstations commonly feature a phase correlation vectorscope, alternatively known as a Lissajous, X-Y, or phase meter (Figure 15). The free and open-source software project FFmpeg offers a command-line tool capable of generating phase correlations with customizable outputs, including a Lissajous using the *avectorscope* command (Figure 16).

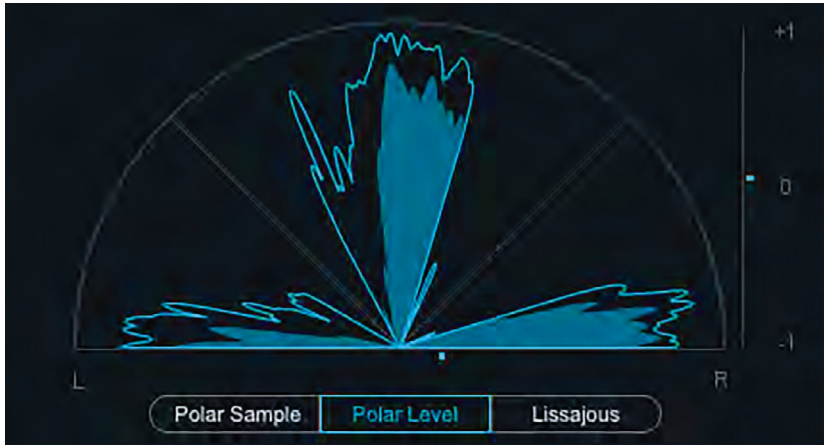


Figure 17. Polar plot and phase correlation meter in Izotope Ozone Vectorscope.

Digital plugins integrated into digital audio workstations can offer additional layers of insight into azimuth errors. An alternative to the Lissajous is observing phase differences through a polar plot, such as in Izotope Ozone's Vectorscope (Figure 17).

Another plugin that can be used to check for errors is Stereo Tool's "Azimuth" section. While this plugin is primarily used in broadcast environments to rectify digital azimuth errors, it can be used to visualize these errors in a real-time running strip chart (Figure 18).

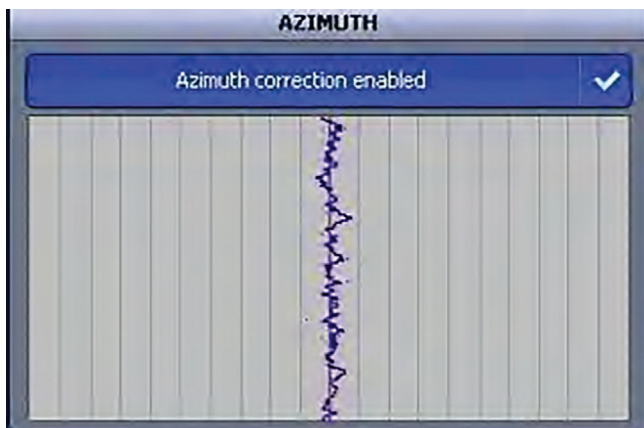


Figure 18. Stereotool (version 10.00) Azimuth showing a running strip chart of azimuth error.

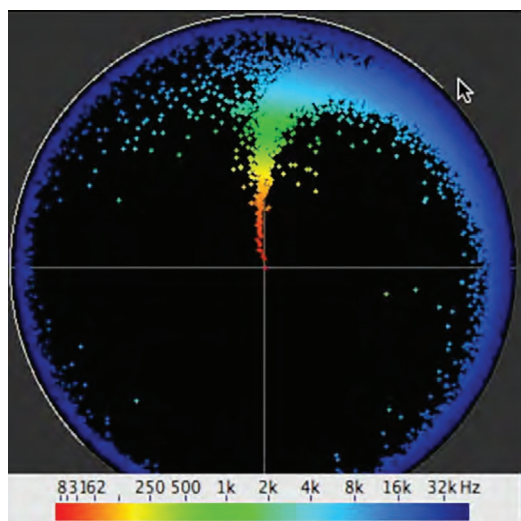


Figure 19. *SpectraFoo Phase Torch showing a signal mostly in phase.*

One notable standalone tool for measuring azimuth error is SpectraFoo's Phase Torch by Metric Halo. The Phase Torch is a frequency-sensitive phase meter that displays phase as a function of frequency (Figure 19). For tapes with azimuth centers that are difficult to establish through listening alone, the analog and digital tools referenced above can help inform the adjustments one makes before and during the transfer process.

Additional notes on compact audio cassettes

For compact audio cassettes, the recording azimuth on the tape is affected by several factors beyond the record head alignment. Elements such as the components within the cassette shell, the recorder geometry, and how the recorder holds the shell add additional variables to the error detection and alignment process. Azimuth issues can arise if the cassette shell is warped, the head or guide components of the player become misaligned, or if the machine has separate record and playback heads. Cassette tapes, typically manufactured at a nominal width of 3.81mm with a tolerance of -0.05mm, may undergo azimuth drift as they traverse the guides on the head, particularly at the cassette's beginning and end (Figure 20). For this reason, it is recommended to start making an adjustment to azimuth towards the middle of the tape first, rather than at either end. Pay careful attention to condition issues such as damage and shedding prior to advancing any tape.

Additional note on larger format tapes

While this guide has focused primarily on the audio cassette and quarter-inch open reel audio tape formats, the principles remain the same for other magnetic audio tape formats. It is equally if not more important to perform head azimuth alignment on larger format tapes, especially multi-track tapes in ½, 1, and 2-inch varieties.

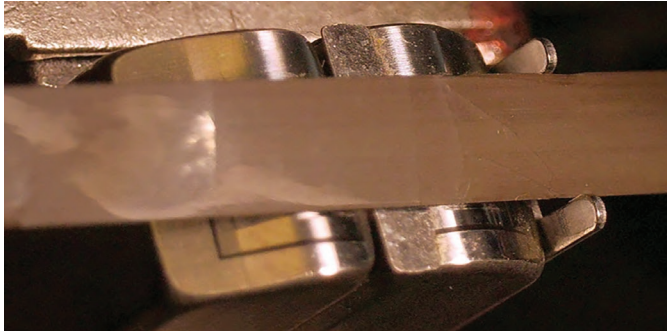


Figure 20. Closeup of cassette tape on head. Note the width of tape is slightly narrower than the guides.

Additional note on digital azimuth adjustment and correction

When transferring tapes which are copies of other tapes, it is important to use the high-frequency level method of azimuth adjustment as opposed to the mono summing method because the physical adjustment of the reproduce azimuth only pertains to the current copy. However, the digital azimuth adjustment tools that adjust phase/timing between channels can correct for the net sum of those errors from every copying stage. These tools will also help correct for gap scatter (a misalignment of the head gaps along the length of the tape).

There is one further head anomaly that is difficult to correct, and that is the case where different tracks have different azimuth. This head defect seems to occur more frequently with butterfly-type heads. In this case, the high-frequency peaks occur at different settings of the azimuth adjustment. If this happens using a calibration tape, replacing the head should be considered. Otherwise, splitting the difference between the two azimuth settings is usually the best compromise. Digital phase/timing correction might also be considered after the transfer..

Basic azimuth adjustment procedure (to program)

1. Prepare tape and machine for playback, including adding leader to head and tail of tape, cleaning, baking, and winding tape for optimum tape pack.
2. Identify program track configuration(s) and tape speed(s)
3. Select the correct reproducer head, playback speed, equalization setting, and reproducer level(s) on machine.
4. Set monitor output to monaural.
5. Play the first few minutes of tape and set course azimuth adjustment by making slight right and left adjustments to maximize high-frequency output and phase correlation.
6. Verify high-frequency output and phase correlation using ears and measurement tools (e.g., oscilloscope, Lissajous, polar plot, Phase Torch, etc.)
 - a. As needed: Play or fast forward to the middle of the tape and repeat adjustments and verification as described in steps 5 and 6. Make a note of adjustments made.

- b. As needed: Play or fast forward to the last few minutes of the tape and repeat adjustment and verification as described in steps 5 and 6. Make a note of adjustments made.
7. Rewind to the beginning of the tape and set azimuth adjustment for the desired output.
- a. Note: For tapes with significant azimuth drift throughout the duration of the recording, some engineers may prefer to manually adjust azimuth in real-time. It is critical to ensure that no additional artifacts, such as pops or clicks, are introduced in this process. If artifacts are noticed in this process, one might settle on an average setting that will yield the least amount of azimuth errors over time.
 - b. Note: In some cases, where a tape is a copy of another recording, it may be more important to match the high-frequency response over the phase correlation. In this special scenario, adjusting azimuth to maximize high frequency of the recording will take precedence. Post-capture, one might adjust the phase correlation to compensate for the differences stemming from earlier analog duplication.

Appendix: common playback decks and tools for adjusting azimuth

- ¼" Open Reel Audio:
 - Studer A80, A807, A810, A820 – 2.5mm Hex
 - Example driver model: PB Swiss PB212.L 2,5
 - Ampex ATR-102, ATR-104 - 3/32" Hex
 - Example driver model: Wiha 26323 (3/32" x 60mm)
 - Otari MX5050 – 3mm Hex Driver
 - Sony APR-5003 – 2mm Hex Driver
- Compact Audio Cassette:
 - Tascam 122 MKII & MKIII (OEM screw) – Philips #0
 - Tascam 122 MKII & MKIII (replacement screw) – 1.5mm
 - Example driver model: PB Swiss 8123.1.5-65

Notes on tascam 122 mkihi azimuth screw replacement

It has been widely documented that the stock azimuth screw on the Tascam 122 MKII and MKIII cassette tape decks commonly used for preservation have a very short life when adjusted routinely for azimuth. In the IASA publication *Locating Replacement Azimuth Screws for Tascam Compact Cassette Decks* (2017), the author recommends replacing the factory screw with a more durable 1.5mm M2x8mm hex screw with a thread pitch of 0.4mm (Figure 21).

The process of replacing the original screw with this new hex one is a relatively straightforward task and can be performed without major disassembly. With steady hands, one can replace the screw with the player in a vertical position to not lose the spring assembly underneath. The full article can be found here: <http://journal.iasa-web.org/pubs/article/view/58/32>. Applying a lubricant like Moly grease can further extend the life of the screw.

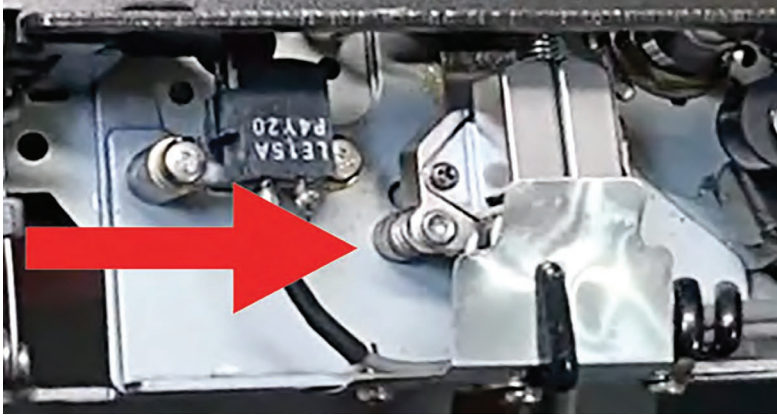


Figure 21. Closeup of replaced azimuth screw (1.5mm hex) in Tascam 122 MKIII.

Additional resources

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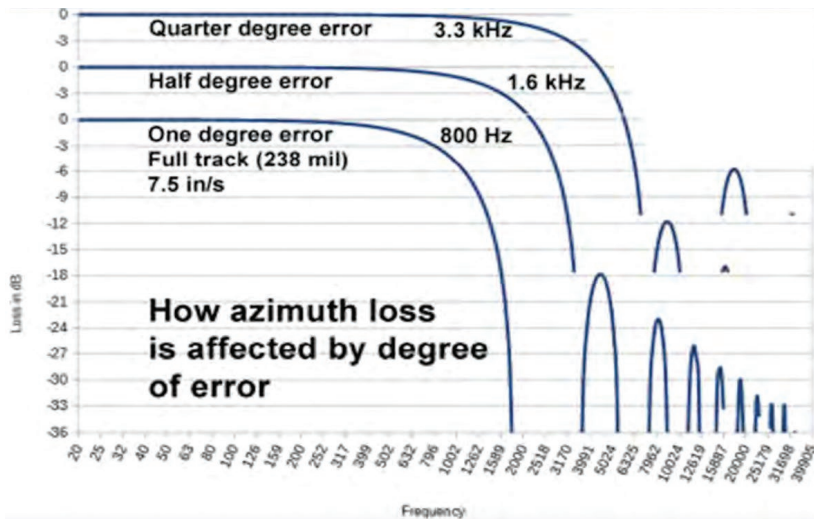


Figure 22. Alternative view of azimuth loss by degree error. Courtesy of Richard Hess.

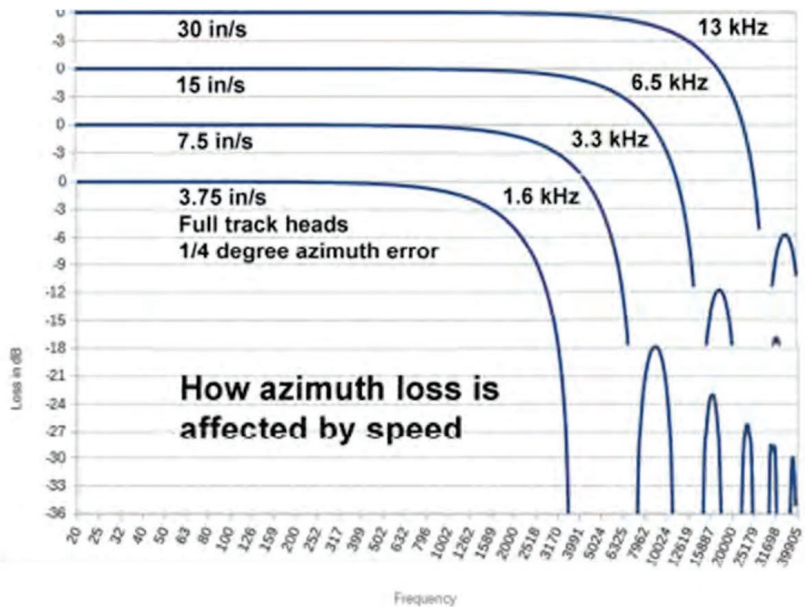


Figure 23. Alternative view of azimuth loss by speed. Courtesy of Richard Hess.

Nicholas Bergh has been working in the field of sound preservation and restoration for nearly 30 years. In 2003, he started Endpoint Audio Labs in order to focus on improving the quality of sound transfers before restoration. Endpoint has become known for both unique transfer technologies as well as using historical research to inform transfer decisions, and has been chosen to preserve some of the most precious studio and public archive sound elements. Projects range from hundreds of tent-pole film titles like *Sound of Music* (1964) and *Titanic* (1997) to hundreds of unique field-recorded elements such as ethnographic wax cylinders and lacquer discs. Unique transfer technologies developed by Bergh are also being used at various national archives around the world. He received his B.A. and M.A. in Ethnomusicology from UCLA.

Richard Hess has been fascinated by tape recorders since the early 1960s. In 1973, he received his B.S. in Communications from St. John's University and joined ABC-TV in New York City becoming an audio-video systems engineer and designing their first multi-track audio sweetening facility. Richard also recorded classical and organ music during this time. From 1981–2004, he worked in audio and TV systems design at McCurdy Radio in Toronto and National TeleConsultants in Glendale, California. In the late 1990s, he saw a need in audio archiving, and in 2004, he started his own audio digitization practice in Aurora, Ontario, working with interview cassettes (including Princess Diana), album masters, and archival recordings (including for a UNESCO Memory of the World collection, ethnographic materials, Oscar Peterson, Anton Kuerti, Stan Rogers, and Manowar).

Dave Walker serves as the audiovisual archivist at the Smithsonian Center for Folklife and Cultural Heritage, where he leads preservation and access initiatives for the Ralph Rinzler Folklife Archives and Collections. He specializes in the conservation and digital reformatting of at-risk analog audio formats and trains others in these practices through workshops, hands-on labs, and international collaborations. Dave contributes to the development of national and international standards for audiovisual preservation. His recent projects include a 2022–2023 partnership with the Tbilisi State Conservatoire and a Fulbright Specialist collaboration in Taiwan, both focused on preserving endangered sound collections and building regional capacity to carry out this work.
