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A Guide to Cassette Tape Transfers

(From the viewpoint of a magnetic recording engineer who has worked in the cassette industry for 20 years, and who is still active as a music lover transferring the MANY cassette and reel-to-reel tapes accumulated over the years to HDD, for preservations sake. H.Hoyt 1/2000)

This guide is intended to provide a foundation for understanding the challenges involved in an optimum recovery and transfer of audio from a Compact Cassette. I also suggest some techniques for dealing with these challenges.

The physical mechanisms inherent in playing a magnetic recording can cause complex problems with the recovered audio, many of which are impossible to correctly compensate for later. When approached from the perspective of its design limitations the Compact Cassette is an unlikely carrier of high fidelity audio. Despite these limitations, it ruled the consumer and semi-pro recording world for years due to it's relatively high fidelity for the time, and small size. Indeed, between the years of 1972 to 1992, it was the subject and beneficiary of most research and advances in magnetic recording, due to its economic potential. Advances such as micro gap heads, advanced head pole piece geometries, high coercivity tape particle formulations, dynamic bias modulation schemes, and some modern noise reduction systems were created initially for the Compact Cassette, only to filter up into the semi-pro and professional reel-to-reel formats.

Unlike open-reel formats, the Compact Cassette (abbreviated from hereon to cassette) has tape steering problems inherent in the shell and slip-sheet carrying the two small pancakes of recording tape. With an open-reel format, establishing correct track placement and azimuth is relatively trivial, and is performed each transfer as a matter of procedure. Engineers who do these transfers quickly become skilled at setting the reproduce head to the azimuth and height of the recorded track, locating the alignment tones at the head of the tape; setting correct reproduce level and a close conjugate reproduce equalization using these tones. At this point all of the major factors necessary to ensure correct reproduction are met. Following the same procedures when transferring a cassette presents the engineer with a far more difficult set of challenges. In this document, I attempt to define these challenges and suggest methods to address them. There are certainly MANY recordings out there on cassette which will never be heard again without some TLC and time taken to transfer them correctly.

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1. What Cassette Deck To Use?

At the cassette tape replication plant where I work as an engineer we use Nakamichi MR-1 decks for mastering and QC work. These decks have been modified by drilling a hole in the cassette well cover/door directly over the Azimuth adjustment screw on the play head. Each mastering engineer, QC person, and technician is issued small screwdrivers to use to adjust the Azimuth on each tape....each side....every time without fail, since it has such a large effect on the recovered frequency response and level.

The venerable MR-1 is long out of production, and there is little choice available for a new cassette deck, all available units being relatively poor performers by 1990 standards. A more desirable alternative is to look for used Nakamichi decks, which are available on eBay for very reasonable prices; of course sometimes they are not in the best shape. A used Nakamichi is a better investment than a used deck of other manufacture due to the extremely long life of the single most critical component: The Nakamichi reproduce head, which due to its unique geometry and materials, achieves better performance for a longer time than others. This means that all else being equal, repairs to a used Nakamichi deck will net close-to-new deck performance, while most other makes will need to have the reproduce head replaced, if it is even still available. We have had some MR-1 decks in constant use in a production environment for over 15 years, and the heads are still serviceable. We use Nakamichi MR-1 decks for mastering and QC exclusively for many reasons, not the least of which is that they have pressure pad retractors on the play head. These spring-loaded felt pads in the cassette shell directly press the tape onto the play head, which is a major source of rough modulation noise most easily heard on pure tones and flutes, as well as female vocals. With these pads retracted from the back side of the tape, the tape movement is much smoother, and the purity of reproduced tones is much better. The deck of second choice would be a Nakamichi Dragon, which has automatic reproduce Azimuth adjustment.   In most circumstances, the Dragon is highly accurate at setting the reproduce head Azimuth to match that of the tape. If the tape being reproduced was recorded with an Azimuth far from the default “zero” correct setting, or if the tape has rapidly changing Azimuth due to shell problems, the Dragon can "hunt" during playback in an attempt to find the correct Azimuth. This can cause a cyclical swishing sound during playback. This being said, I often use a Dragon at home to play back my own recordings, and usually achieve great results.

Many other individual high-end models by manufacturers such as Sony, Denon and Tascam can be used successfully with little modification. I have less experience to share with any other models, so all my suggestions apply to using Nakamichi decks.

Enough said regarding choice of deck. Financial or other constraints will dictate the deck that you will use to do transfers.

2. Mechanical Reproduce Head Alignment

2.1. Reproduce Head Azimuth

The single largest factor standing in the way of recovering a signal from a cassette is the Azimuth match (or mismatch) between the recorded tape flux and the reproduce tape head gap. Azimuth in this case is defined as the perpendicularity of the recorded lines of flux on the recorded tape track to the longitudinal direction of tape movement. The average Azimuth mismatch of 5 to 15 minutes of arc occurring during reproduce can reduce the high frequency level recovered from the tape by 3-8dB @ 10kHz. Equally bad, it throws a time delay between the L and R channels, which throws the stereo image off center, and causing phase-interference comb filtering in the audible playback. If this doesn't mean much to you, lets just say a bad Azimuth mismatch between the tape and head makes the sound muddy and without good stereo imaging. Ideally, the play Azimuth is adjusted to the tape Azimuth for each tape side played. There is a HUGE variation in tape shells (the cassette tape housing), cassette holdback and take up tension, tape surface friction, condition of pinch rollers, and the Azimuth of the record head used to make the recording, which all contribute to steering the tape to a non-ideal Azimuth.

The Nakamichi Dragon cassette deck automatically rotates the head around the centerline of the stereo track pair to maximize high frequency content recovered from the recording, which will usually result in a correct Azimuth match between the tape and reproduce head. For other decks, you can manually adjust the Azimuth by turning the Azimuth adjustment screw on the take-up side of the reproduce head (the one some locking paint on the screw head, and with a spring under it) with a #0 Phillips screwdriver. Adjust it while listening to a portion of the recording with the most high frequencies, like a ride cymbal. The adjustment is very easy to make correctly using just your ears. To make the adjustment even easier, put the monitor into mono, which will sum the L and R channels together. Summing the channels will make the signals from the L and R heads constructively add when they are in time alignment, sounding bright and normal, and when off optimum, sound dull as the time offset (phase) between the channels changes. This time offset causes the signals from the two channels to destructively interfere with each other, canceling the high frequencies.

OK, so you have successfully set Azimuth and transferred the recording: "How do I know to correctly reset the deck Azimuth back after transferring my tape?" you may ask. Unless you plan to use the deck for recording, "correct" for head alignment is whatever makes the high frequencies the highest level with each tape side you reproduce. So if you plan on only using the deck to reproduce, plan on setting the Azimuth for each side of each tape you play. It is usually simple to perform, and it is the single most important factor affecting correct reproduction of a cassette tape.

2.2. Reproduce Head Height

The cassette is a 4 track format, with two pairs of stereo tracks separated in the middle by a guard band. Steering influences in the cassette shell and deck will cause the tape to slide on the head at right angles to the direction of travel. This causes a misalignment between each recorded track on the tape and the individual track pole pieces and gaps of the reproduce head. In severe cases, it can cause the left (edge) channel to greatly reduce in level, and the right recorded channel on the tape to partly overlap the left channel head gap. The main symptom is a level imbalance between channels, although severe Height steering is usually accompanied by an Azimuth change. This adjustment is most easily made on a Nakamichi deck with discrete Azimuth and Height adjustment screws. On other decks, Height can only be adjusted by the use of shims under the head attachment screw opposite the end with the Azimuth adjustment screw and spring. The correct Height setting is the one which optimizes both channels output levels. If they do not both peak at the same Height setting, set it in the middle of the two peaks. The challenge when adjusting Height on any deck is simultaneously keeping Zenith and Azimuth correct while the correct Height is found.

2.3. Reproduce Head Zenith

This parameter is set at head installation, and is not directly adjustable. It is checked by means of a reference flat platform which sits in the cassette well, and a precision right-angle square to place against the tape head. The right angle of the square should fall perfectly flat against the face of the head at the magnetic gap without any wedge shaped air gaps visible. Without the correct setup jigs, it is inadvisable to attempt to correct Zenith.

Adjusting it is easy on a Nakamichi with independent adjustments, on other decks it will be a matter of bending the head mounting strap carefully with fine needle nose pliers (CAUTION! This can cause the head to break off of the mounting strap, and correct reattachment can be impossible!). If after setting Zenith the tape steers badly against the guides, there is probably a major issue with pinch roller or capstan wear, or insufficient hold back or take-up tension.

3. Electronic Reproduce Alignment

3.1. Reproduce Level

There were two major standards used during the heyday of the cassette to define "0dB" in the cassette format: 160nWb/M and 250nWb/M, the latter also being used as the reference Dolby calibration level. Manufacturers of cassette decks also used many different reference levels as the "0" for metering purposes. For the purpose of setting up reproduce level, first decide if the recording was Dolby encoded, and if it was not, then level adjustment can be done with either the deck's output level control, or the computer's record level. If the tape recording WAS Dolby encoded, the correct reproduce gain before the Dolby decode must be set. Since record/reproduce level is evaluated at 400 Hz, and this low a frequency is usually not affected by most minor tape misalignment, the factory default gain settings are usually close enough for almost all tapes you will be reproducing. If dynamic modulation (pumping) is noticed when Dolby decode is turned on, and the frequency response seems correct, then an adjustment of the reproduce gain may be necessary. Correct setting in most cases can be achieved by placing a reference 400 Hz level set cassette in the deck and adjusting the repro gain pots using manufacturer's procedures. Changing the reproduce gain to a different setting may be necessary to correct for a poorly made Dolby encoded tape, and will have to be done by ear.

The easiest way to set transfer levels to a PC is to first transfer the entire tape side or whatever is of interest at some relatively low level. Then using a program such as Sound Forge go to the menu item: Tools>Find>Find Largest Peak (find maximum value) to locate the time at which the highest level occurs. After finding this peak level, go back to the original tape at that place where the peak occurred and change the analog play/output level of the deck to set the PC record level to approximately 1dB or less under clipping at that peak. Many people find that level setting using this technique results in a digital file with abnormally high average levels. This is due to the fact that cassettes in general have much less dynamic range than today's CDs, as a result when the level is set using the peak level as the reference the average is higher. Setting levels by peak reference ensures that no peaks are clipped in the transfer, and retains as much dynamic range as possible. One benefit of setting levels this way is that later equalization operations (I advocate using only "cut" equalization, and then only when absolutely necessary) which take away signal will not too adversely affect the final signal to noise ratio.

3.2. Reproduce Equalization

Reproduce equalization is divided into two separate processes: The inherent equalization type with which the tape was recorded, and subsequent equalization to compensate for response errors encountered during reproduction.

3.2.1. Equalization standards.

High frequency equalization was designed into the initial IEC standards for the cassette format. The equalization is applied as a boost during record, and a conjugate cut during reproduction. There were two different equalization standards settled on for use with different tape types: 120uS for ferric (Type I) and 70uS for “high bias” $FeCrO_2$ and Metal (Type II) tape. 120uS was deemed to be an adequate compromise initially due to the boost in the record phase. It was necessary to limit the amount and corner frequency of the boost to keep from over saturating early ferric oxide type tapes. With the development of tape types with higher saturation fluxivities in high frequencies, such as $FeCrO_{2,}$ CrO_2, and Metal types, a decision was made to further increase the signal to noise ratio of the system by additional high frequency boost in record using a 70uS equalization, with the corresponding cut in reproduce.

An additional issue reared it’s ugly head by the late 1980’s, when it was apparent that decks of Japanese and other Asian manufacture were being designed to have a reproduce equalization which incorrectly reproduced the then IEC standard BASF reference frequency response tape. My company performed extensive investigations into the nature of this error, and discovered that nearly all decks made in Asia were set up to reproduce the Japanese ABEX brand reference tape correctly, not the BASF one. This choice would allow the manufacturers of the decks to substitute less expensive tape heads and trade off the increasingly higher tape high frequency headroom, thanks to advances by tape manufacturers. The difference was a high frequency boost on the ABEX tape. The result was that cassette decks using the ABEX tapes as alignment standards would require additional high frequency pre-emphasis on the recording in order to not sound dull. The situation caused a schism between Europe/USA and Asia in terms of whose standard was prevailing. At the time, the US and European cassette replication industry had been using the BASF reference tape as our standard, and tapes made in replication plants so set up had reduced high frequency content when played on cassette decks of Asian manufacture, which was unfortunately 99% of the decks on the market! Once we realized this, we immediately switched our in-house reference standard to the ABEX tape, and much better reproduction of high frequencies was immediately noticed by our customers. As a foot note to this situation, Nakamichi alone of all Asian manufacturers had continued to follow the initial IEC equalization standards, and through research and development of superior heads, achieved superior performance with the same tape stocks. This situation led to a misguided rumor in hifi circles that Nakamichi decks had their “own” standard and were incompatible with other decks.

Practically speaking, most cassettes can be properly played back with the reproduce equalizer set to the correct one for the tape type. In certain circumstances where a Type II tape recorded with 70uS equalization is somehow extremely dull on reproduce, a possible band-aid is to switch the reproduce equalization to 120uS.

3.2.2. Post-Reproduction Equalization.

If a cassette is recorded and reproduced correctly, no corrective equalization need be employed. If there are errors in the frequency response due to incorrect recording or storage loss, there are two different approaches, the correct one dictated by a determination of whether or not Dolby encoding was employed in the record phase (see the section on Dolby for details). If it is determined that no Dolby encode was used in the recording, then equalization can be performed externally to the deck with good results. If, on the other hand, Dolby encode WAS used to make the recording in question, the equalization problem is only correctly dealt with by equalization introduced BEFORE the Dolby decode. This can be achieved in the case of the modified Nakamichi MR-1 by inserting an equalizer into the rear-panel external NR jacks which have been modified to be allow for pre-Dolby decode equalization. This will allow you to correct the equalization to compensate for the loss mechanisms encountered in the encode>decode loop pre-decode. As a result of this approach, the Dolby decode will track properly, restoring correct dynamics as well as high frequency content. The only sacrifice will be a slight reduction in the signal to noise ratio and dynamic mistracking due to the boost equalization and resulting additional noise. At worst, it is far superior to adding equalization post-Dolby decode, which retains the dynamic high frequency mistracking of incorrect Dolby decode, and further increases the objectionable nature by boosting these high frequencies post-Dolby decode.

3.3. Reproduce Tape Speed

The design tape speed for a cassette is 1.875 Inches per Second. Of course, reproducing a tape at this speed will only correctly reproduce a tape that was recorded at the same speed. I advocate only using the electronic speed adjust in the cassette deck to correct for a speed error. Although this is not as “convenient” as using the digital speed adjustment in a computer, adjusting the actual speed of the tape reproduction causes none of the digital error in the final file due to the use of speed change functions in the editing software. In order to "speed up or slow down" music in the digital domain, new samples must be created or samples taken out of a digital music file in order to effectively change the duration of the file. The sound of this is easily demonstrated by dialing in a large, say 2:1 speed or pitch change into a file. The resulting grainy, odd sounding effect is typical of what is brought into a file using an editing program speed change algorithm. Yes, the undesirable sound change due to an extreme 2:1 speed change ratio is greater than that usually found when performing minor speed corrections, but the same distortions are introduced to a lesser extent by any digital speed change process.

By using the electronic speed adjust on the cassette deck, accepting this undesirable side-effect becomes unnecessary. The sonic benefits can be as large as the required speed change needs to be. If there is not a front panel speed adjustment, a service manual for your deck will show the correct location of the potentiometer which sets the speed. Nakamichi decks vary in the location of the speed adjust, which can be found either on the motor PCB or inside the motor end shell. On non-Nakamichi decks with a single capstan motor, the speed adjustment potentiometer is often on a circuit board inside a small round hole in the back cover of the main motor. If you attempt to change the speed on a deck where the potentiometer is inside the end bell of the motor, use a jeweler's screwdriver, and wrap a few turns of tape around the blade, to keep the screwdriver from shorting the potentiometer to the case of the motor.

4. Reproduce with Dolby Decode or Not?

4.1. The Dolby System Overview

This issue seems to polarize people as a matter of opinion, despite the fact that without the 1968 introduction of Dolby B, the raw Compact Cassette format at 45dB S/N ratio could hardly have been called high fidelity. In reality, the decision of reproducing a cassette with or without Dolby is not a matter of one's opinion of Dolby B, rather it is dependent on whether or not the tape was encoded with Dolby B during record. (For the purposes of this discussion only Dolby B will be considered)

Dolby B is an Encode/Decode process where the high frequencies are compressed before being recorded, then re-expanded during reproduction. This reciprocal action is commonly called Companding. Dolby B uses a unique sliding band companding scheme, where the corner frequency of the Dolby action can be as low a 300 Hz or as high as 20,000 Hz. Dolby B has no action on loud signals or material below 300 Hz. The net result in a correctly designed record/reproduce situation is that the high frequencies are restored to exactly the original spectral and time relationships as in the original source, and the tape noise is reduced by the amount of decode downward expansion, usually around 10dB. When properly implemented and utilized, the Dolby B type noise reduction has acquitted itself in critical listening tests as a very high fidelity noise reduction process. That being said, the possibilities for error are numerous and commonplace.

Consider that because it is an Encode/Decode process, level and equalization MUST be preserved between the encode and decode for the original content to be recovered. The following are factors which are inserted in the cassette tape record/reproduce signal path BETWEEN the Dolby encoder and decoder: the recorder level, equalization and bias settings, the tape stock's dynamic compression characteristics and long term signal loss, Azimuth and Height mismatch between the recording on the tape and the reproduce head, and reproduce level and equalization. All of these sources can and will add up to cause frequency or amplitude domain errors, which will cause Encode/Decode mistracking of the Dolby process, with a resulting reduction in recovered fidelity.

All of the factors that affecting a correct Dolby B encode/decode process should be corrected for individually and in a conjugate manner to the error mechanism itself for optimum transfer fidelity. Starting with the recorder, any misalignments cause errors in the actual recording on the tape which permanently affect the recorded signal on the tape itself. Therefore the correct strategy is to compensate with the reproduce conditions to as great an extent as possible. This means the first set of factors to optimize are the mechanical alignments of the reproduce head to the magnetic lines of flux (the recording) on the tape. Refer to the section on tape head alignment for details on performing this adjustment. Once the tape recording is tracking correctly on the reproduce head, the next factors to adjust are the reproduce level and equalization. Refer to the section on reproduce level and equalization for details. After performing an electrical reproduce alignment, you are ready to evaluate the tape for its Dolby characteristics.

4.2. Evaluating a tape to determine if it was Dolby encoded

Listen to the recording with Dolby B decode engaged, then with it out. The most obvious effect, and the one that convinces those people who are ignorant of the nature of Dolby that “Dolby sucks”, is the high frequency content difference. Since the Dolby decode is a downward expansion of high frequency content, there is “more” high frequency sound reproducing a tape with Dolby decode turned off. But here is where we ask the $1000 question: What was the high frequency content in the initial material? Most people concerned with high fidelity do not want more high frequencies when reproducing a tape recording then there was in the original source. Therefore the correct way to do the evaluation is to know what the original source sounded like. If this is an unknown, the dynamic effects of Dolby encode can be heard on many recordings if the Dolby decode is turned off. Remember that the Dolby process is a conjugate encode/decode to both the high frequency levels and dynamics. If the tape was recorded using Dolby, I usually find it objectionable sounding with Dolby off. The dynamics are modulated and sound unnatural, an effect often called "pumping". Pumping is most easily identified as an unwanted dynamic modulation of a lower frequency by the high frequency material. I find this highly irritating, since there is no analog to this in the natural world.

If this effect is heard when Dolby is off, then it is correct to reproduce that particular tape with the Dolby decode on. OK, you say, I am with you so far, but when the Dolby is turned on, the high frequencies drop to a point where the tape sounds dull, i.e. less high frequency content than the original source. There are three different ways to compensate for this, one correct and more difficult, two are easier but achieve inferior results. The correct way to fix the high frequency loss and retain correct Dolby decode is to modify the reproduce level and equalization of the deck to restore as closely as possible the original spectral balance so the Dolby decoder can perform a correct conjugate restoration (refer to the section on repro level and equalization for details). This is difficult to perform correctly on a tape by tape basis, and the controls built into the deck to do this are not intended for frequent use, and are often inaccessible. The two easier but less correct methods are to perform a post-Dolby equalization to bring back up the high frequency level, or to take the Dolby decode off and suffer with the dynamic errors of the undecoded compressed high frequency content. This may, however, sound better than some cases of severe Dolby reproduce mistracking that can occur if the source was encoded with Dolby B and then recorded very poorly.

In more practical terms, the easiest way to determine what to do about Dolby decode is to experiment with the Dolby both on and off, trying not to pay attention to the drop in the high frequencies that turning the Dolby decode on will induce. These can be equalized back in, if the loss is not too severe. Pay attention instead to the dynamic pumping of the noise floor, or to a cymbal decay as louder high frequencies (HF) play in the foreground. To transfer a type II tape, I first try Dolby on with the equalization set to 70uS/typeII. If the HF dynamics sound good, with natural sounding reverb tails, I usually transfer in this manner, and do an HF equalization afterward to the entire recording. If it does not, I then switch to Dolby on, equalization set to 120uS/typeI. This is usually as much as I need to do to recover the correct HF dynamics on a tape recorded WITH Dolby....

5. Common Cassette Shell/Tape defects

5.1. Sticktion Squealing

The sticktion squeal manifests itself as a squealing which is modulated by the recording, with little or no squeal where there is no recording. This type of tape squeal is actually a speed modulation akin to a Frequency Modulation of the recording. If there is no recording, there is nothing to modulate. In some cases, an audible squeal actually comes from the cassette itself as well. This noise is commonly associated with tapes manufactured between 1970 and 1988 which used a partly stabilized urethane binder. (note: ALL my old TDK cassettes now do this….NONE of my old Maxell cassettes do this) After a few years of storage, the binder uptakes moisture and degrades, turning sticky. When you attempt to play the tape in the degraded state, the binder sticks and releases to the heads and other stationary guides in the tape path. In worst cases, binder and oxide (read- the recording itself) can come off on these heads and guides, making the recording impossible to recover. There is only one possible remedy I have done that actually works: tape baking. This is a technique developed by Ampex engineers, where a tape is baked at a constant dry heat of 125 degrees F for 8 hours, then allowed to come back to a stable room temperature. I have done this to MANY cassette and open reel tapes, with varying success. I used to remove the pancakes of tape from the cassette to facilitate the baking, but after a few disasters, have begun leaving them in their shells. There are a few critical words of advice: DO NOT USE A TOASTER OR ANY OTHER OVEN! The idea is to use constant 125 degree F hot air, not radiant heat of an unknown and cyclical nature. I now use a food dehydrator with multiple shelves, and partially restrict the air intake with tape to raise the air temperature to the 125 degrees F needed.

5.2. Broken Tape

There are still cassette splicing kits available from professional audio supply stores, and fixing a broken cassette is very similar to doing the same job on open reel tape, just more difficult due to the thin tape. If the tape leader has broken off of the hub, it is usually possible to split the cassette shell and pop the hub lock out and replace it with the tape secured in place. Switching the cassette tape pancakes from a sonically welded shell to a screwed shell is advisable in this case. Just make sure that the hubs do not interfere with the shell halves of the new shell before screwing them together, and that the reels move freely with the shell halves screwed together.