DOI: 10.2352/issn.2168-3204.2016.1.0.81

Digitizing 16mm, 35/32mm, and 35mm Optical and Magnetic Sound Elements

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Abstract

Deluxe's audio group (formerly known as Chace Audio) has been migrating optical and magnetic film sound elements for nearly 30 years and has developed unique and proprietary technologies to do so. Successful digitization of these elements for archival / post-archival purposes requires an in-depth understanding of the various types of physical damage and deterioration commonly found in them. These conditions can affect the stability of transfer machines and, consequently, the quality of the resulting digital audio recordings. This paper will showcase examples of physical damage and deterioration that adversely affect digitization along with the solutions developed to overcome them.

Physical Element Deterioration

Since the advent of optical sound recording in the early 20th century, sound has been recorded on film for a variety of uses including military, news, television, and motion picture exhibition. The earliest optical film sound tracks are now close to 100 years old, with early magnetic film sound tracks over 65 years old. Physical asset preservation is critical to ensure that original elements survive the test of time in the best possible condition. However, despite best efforts, many elements have already suffered gross deterioration that make them very difficult to play back, if not impossible, and others continue to deteriorate over time.

Naturally there is both a need and desire to combat this physical deterioration by copying legacy sound recordings to more stable carriers. While some archives are still creating analog optical and / or magnetic audio copies, most are now entirely focused on physical asset digitization, creating audio files that are easier to access, distribute, and migrate over time.

Aside from the availability of playback machines, physical damage and deterioration is the major cause of problematic digitization of these elements. As sound playback devices are mechanical in nature, physical defects can create machine transport issues that are audible in the resulting audio files. Examples of this are wow, flutter, slewing, and loss of head contact (magnetic sound tracks) which can lead to audio mutes and level drops. Other anomalies not directly related to machine transport issues include high noise floor, signal loss, crackle, pops, and ticks.

In the case of optical film sound tracks, the demise of film laboratories creates yet another challenge when digitizing these elements. This is particularly relevant when dealing with damaged optical sound track prints (OSTPs). Archivists have traditionally resorted to the optical sound track negative (OSTN) when an OSTP exhibits audio issues, creating a new OSTP at a film laboratory from the more pristine OSTN. Now that it is increasingly difficult to find laboratories that are able to create a positive soundtrack print, due to diminishing and more expensive film supplies and the lack of an experienced staff to create them properly, optical sound scanning technologies are quickly becoming a necessity.

Archives have embraced digital film scanning for visual materials, and many film scanners feature sound scanning, but the quality of the sound scanning, along with the formats that these scanners can handle, is limited.

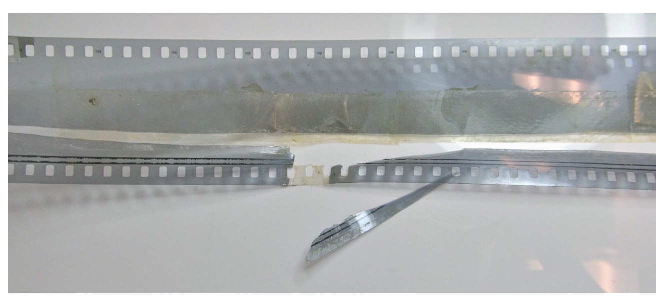
Deluxe's audio team has over 30 years of experience dealing with these issues and has developed solutions to overcome them in an effort to create the best possible digital sound recordings of these elements. These solutions include cleaning and revitalization techniques, along with specialized playback systems.

Element Inspection and Repair

Before any aging optical or magnetic film sound recordings are transferred, it is critical that they be carefully inspected in a clean-room environment for physical damage and prepared for playback. This includes the addition of film leader to aid in machine threading and core replacement when necessary. Any physical defects that could affect the transport of a film element on a playback machine need to be addressed prior to attempting a transfer, or further element damage is risked due to the machine tension and sprocket-driven transport systems used on many machines. Additionally, elements must be clean and free of dirt and dust for optimal audio quality.

Aging optical and magnetic film sound tracks exhibit common physical film defects such as perforation damage, poor or deteriorating splices, and tears that can be repaired during the film inspection process using several well-documented and accepted methods such as the application of splice and perforation tape. Thankfully, audio specialists can repair serious physical defects when these techniques are applied with precision and care, as shown in figures 1-4 below.

Figure 1



Example of physically damaged 35mm optical film sound track negative before repair.

DOI: 10.2352/issn.2168-3204.2016.1.0.81

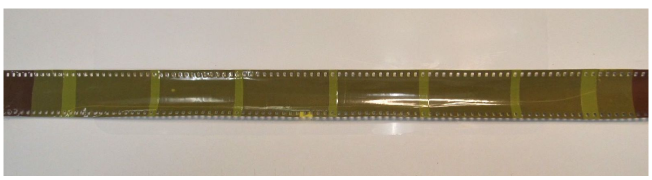
Figure 2

Example of physically damaged 35mm optical film sound track negative from figure 1, after repair.

Figure 3

Example of physically damaged 35mm magnetic film sound track before repair.

Figure 4



Example of physically damaged 35mm magnetic film sound track from figure 3, after repair.

Element Cleaning

Optical Film Sound Track Cleaning

Optical sound track negatives and positives can be cleaned using commercially available film cleaning machines featuring ultrasonic agitation, such as a Lipsner Smith, which is able to remove excessive dirt, grime, smudges, and more. For less intensive cleaning aimed at removal of only small pieces of dust, dirt, and lint, we've modified an existing MTM film dubber with Particle Transfer Rollers (PTRs). This machine is used before or after manual cleaning, which incorporates various cleaning solutions dependent upon the film base and degree of cleaning required. These methods are highly effective and widely used by archivists around the world.

Magnetic Film Sound Track Cleaning

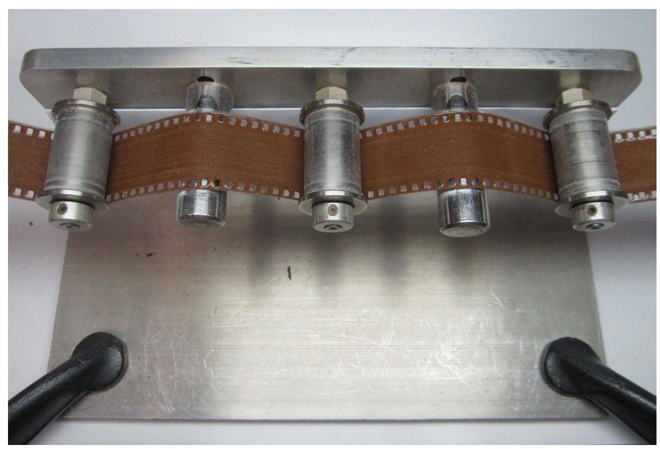
Magnetic film sound tracks can be more difficult to clean than optical film sound tracks due to vinegar syndrome related issues. Vinegar syndrome, or acetate film base degradation, is a complex chemical reaction that occurs in acetate-based film stocks that causes them to decompose. It can affect both optical and magnetic film, but it is typically more common and advanced on magnetic film sound tracks. This is because the magnetic oxide accelerates the deterioration process, which releases acetic acid, resulting in the vinegar smell that it is named for. Much has been written about this issue and it is well known that the condition can spread from affected elements to unaffected elements. It is recommended that any elements suffering from vinegar syndrome be stored separately from other elements in your collection. Additionally, storing affected magnetic elements at low temperatures (35-40 degrees Fahrenheit) with low relative humidity (30-40%) can slow down the process, prolonging the life of the film.

Film affected with vinegar syndrome does not just smell bad. It also affects the transferability of the film as degradation increases. Symptoms include shrinkage, warping and buckling, soft emulsion, brittle film, and plasticizer discharge. Plasticizer is added to the film base during the manufacturing process. As the film begins to decompose, the plasticizer can crystallize, appearing as a thick white powder on the surface of the magnetic film. Soft emulsion and plasticizer crystallization can build up on the sound heads during transfer. This build-up affects head contact and loss of high frequency reproduction, resulting in a muffled, dull transfer [1].

Burnishing

One of the most simple and effective methods for removing soft emulsion and light plasticizer build-up is the use of burnishing bars. By running the film across specially designed burnishing bars, build-up is gently reduced or removed, as shown in figure 5, enabling vastly improved high frequency reproduction.

Figure 5



35mm magnetic film sound track being run across our burnishing bars from left to right. The white plasticizer build-up is gently removed so multiple passes are often required for heavy build-up.

Alcohol Treatment

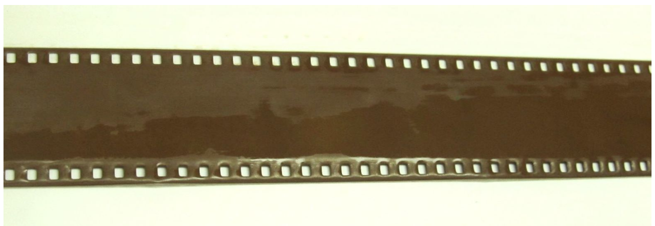
When plasticizer is heavier and more embedded in the magnetic emulsion, a denatured alcohol treatment can be used to remove it. This can be a very time consuming process when done manually, but the results of careful cleaning with alcohol treatment are clearly visible in figures 6 and 7. Great care must be taken to ensure that alcohol is not over-used or it can damage the film by drying it out, or conversely, make the film very soft, causing the film to fold over.

DOI: 10.2352/issn.2168-3204.2016.1.0.81

Figure 6

35mm magnetic film with heavy plasticizer build-up, before alcohol treatment.

Figure 7



35mm magnetic film with heavy plasticizer build-up from figure 6, after alcohol treatment.

MFCM

In order to accelerate the cleaning process, Chace Audio technicians designed a Multi-function Magnetic Film Cleaning Machine (MFCM), which combines multiple processes into a mechanically automated machine to reduce soft emulsion and plasticizer build-up [1]. Manual cleaning is still Deluxe's preferred method because it allows technicians to better control the wind of the film to help with warping, but the MFCM is a good option for less warped elements.

Transfer Assist Methods

In extreme cases, the emulsion is too soft or the plasticizer too heavily embedded in the film for burnishing, alcohol treatment, or use of the MFCM to sufficiently reduce these conditions, making an efficient high-quality transfer very difficult. Technicians at Deluxe have even resorted to transfer assist methods in order to prevent head clogs, sticking, and/or loss of high frequency content. These transfer assist methods are considered a last resort as they can reduce the longevity of the film element, but in cases where it is being attempted, the element is generally unable to be transferred without them.

For soft emulsion that is causing sticking, a small amount of baby powder can be applied to the film. This allows the emulsion to move across the magnetic play head smoothly, without sticking and jerking during playback. The powder is removed from the film after it crosses the play head by running it against a roll of Pellon fabric before it is wound onto the take-up reel. The process can be messy and the machine needs to be thoroughly cleaned after the transfer is completed. Additionally, the granular nature of the powder wears the audio heads down quickly, reducing their longevity.

For heavy plasticizer build-up that affects high frequency response, an alcohol drip system can be used to continuously clean the film before it crosses the play head (see figure 11). The excess alcohol is then dried off the film before the take-up reel. This can be highly effective, but must be closely monitored to ensure that the drip frequency is just right so that the alcohol is not over or under-applied.

Lastly, for use in only the most extreme cases, Chace Audio developed a proprietary non-hazardous anti-friction transfer assist lubricant called ThomSlick™ that enables the physical transfer of film elements with extremely soft emulsion or heavy plasticizer build-up. This can been used on magnetic elements where the vinegar syndrome is so advanced that emulsion is peeling severely, the element is severely cupped and shrunken, or when sections of magnetic oxide are separating from the acetate base and hanging off of the film. It can also be used when the magnetic film is so dry, brittle, cupped and shrunken that it is difficult or impossible to unwind.

This is a last-resort solution that technicians should only use in the most extreme cases of magnetic film deterioration on elements that are otherwise completely unusable. This trade secret formula is difficult to apply to the film and even more difficult to remove. It also has a capillary action, so it will find its way through cracks and holes and will spread quickly within the area it is used. Because of this, elements slated for "slicking" are aggregated and specific dates selected for the preparation of the film and transfer area. Clean up of the transfer room can take up to a day after transfers are complete.

Despite all of these drawbacks, it is used in situations where no other methods are available for a successful transfer and, once applied, the film will slide over the play head without any difficulty.

Hydration

When magnetic film reels are severely dry and brittle and will not unwind due to cracking and breaking, hydration methods have been developed to soften the film enough for transfer. Film in this condition typically requires one to two weeks of hydration treatment in one of our specially designed hydration pots before it is soft enough for transfer. It must be transferred immediately after it is removed from the pot or the film will quickly harden again.

Several improvements have been made to our process over the years and results have been very good, as illustrated by the before and after results in figures 8 and 9.

Figure 8

Severely dry and brittle 35mm magnetic film reel in need of hydration.

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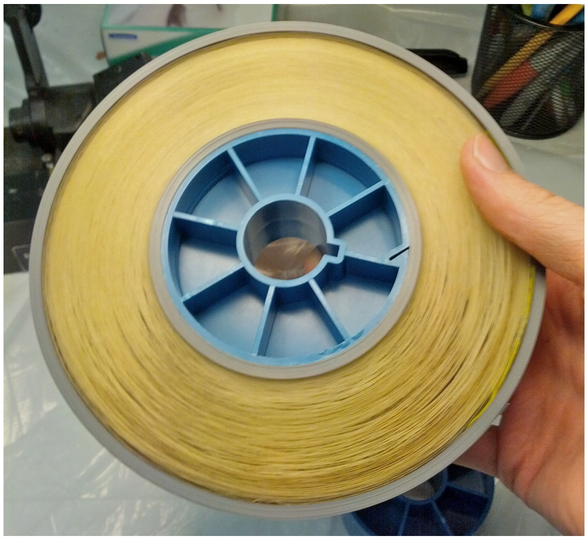
Figure 9

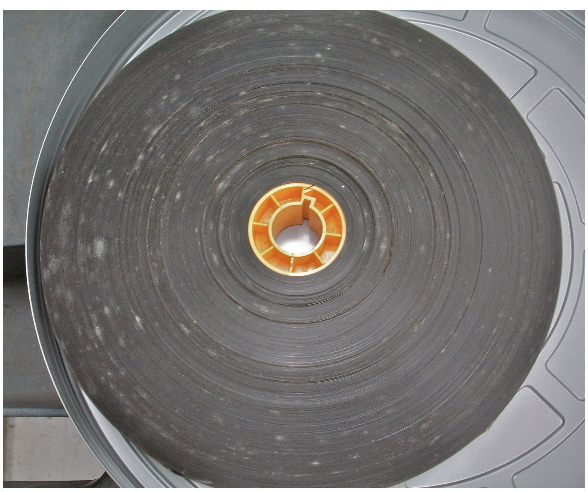


Severely dry and brittle 35mm magnetic film from figure 8, after hydration.

Mold Abatement

Film reels containing mold (Figure 10) can also be treated using a custom-designed mold abatement process called THOR (Tactical Hyphae Obliteration Rig). This trade secret process utilizes UV-light technology to inhibit, neutralize, and remove mold from affected film reels. Once mold has been removed, reels can go through a drying process if needed and be moved on for standard film inspection and prepping.

Figure 10



Film reel containing mold spores.

Playback Solutions

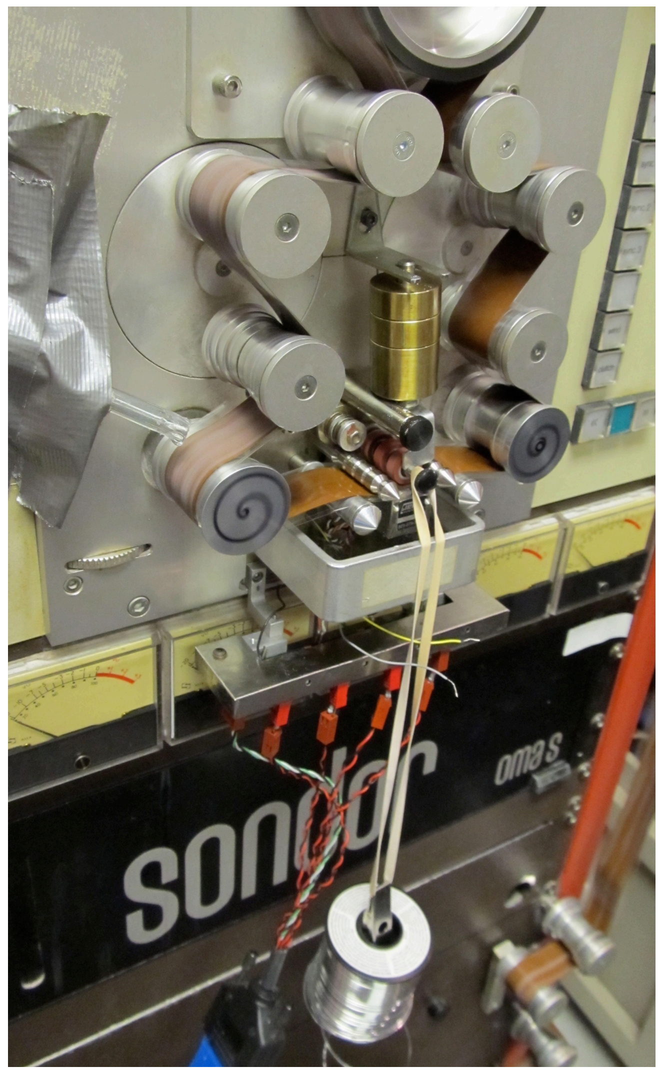
Once aging film reels have been properly inspected, repaired, and cleaned, they are ready for transfer. However, they often still exhibit warping and shrinkage that require specialized playback solutions.

Magnetic Film Sound track Playback

Working directly with Sondor in the late 1990's, Chace staff contributed to the development of the Sondor OMA-S (and later OMA-E) magnetic film reproducer. This collaboration resulted in key improvements over a standard magnetic playback machine that include extra guide rollers and guiding posts on the head stack, a retractable pressure-roller assembly on the playback head, sprocket rollers to cope with up to 4% of shrinkage, larger flanges on all idler rollers through the entire film path, independent torque adjustments for the supply and take-up reels, and film tension adjustments inside the closed-loop and over the sound head. Since its development, it has become a standard choice for archival sound transfers throughout the world.

Even with all of these added features, some film is so warped and un-wieldy that Deluxe technicians occasionally have to add additional weights to the pressure-roller to maintain constant film contact against the playback head, as shown in figure 11.

Figure 11



A Sondor Chace OMA-S magnetic film dubber with an alcohol IV drip (upper left), weighted pressure-roller, and custom-built Clarity sound head.

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Additional playback solutions have been developed for magnetic film sound tracks since the Sondor OMA Chace model, including the MWA MB51 magnetic film player with its Laser Shrinkage Detector (L.S.D.). The L.S.D. modification kit enables the MB51 to play back shrunken film up to 4% using a sprocket-less wheel and laser light barrier to detect perforations and control playback speed. Because there is no sprocket reel, the L.S.D. system works when the shrinkage rates vary during playback.

Regardless of which playback solution is used, there are times when wow and flutter are still induced due to the condition of the film elements. These speed fluctuations were previously uncorrectable post-transfer, but there are now software processes, including CEDAR Respeed™, Celemony Capstan, and Plangent Processes, that allow for post-transfer wow and flutter correction. Of the various processes, Plangent Processes is unique due to its ability to correct speed fluctuations by recording the bias signal off of the original magnetic recording using custom-built playback heads. The bias signal is then used as a timing reference for speed correction of the digitized audio. This allows for objective speed correction that is not based on analysis of the audio signal itself, which can lead to subjective correction results, but rather the original bias signal recorded onto the element when it was created.

Optical Film Sound Track Playback

There are two basic types of optical sound tracks: variable density (VD) and variable area (VA).

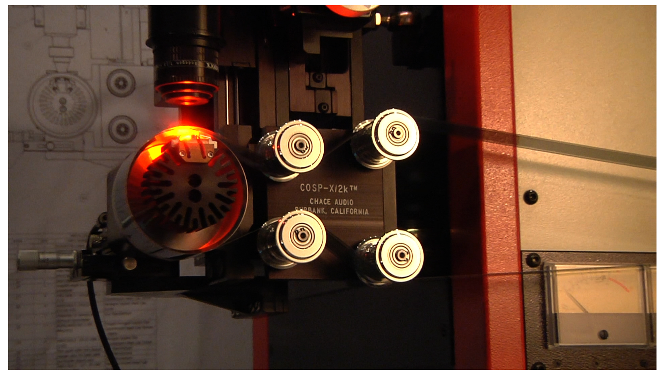
Playback of optical sound track prints (OSTPs) is relatively easy using a common light and photocell playback system (VA and VD) or an image scanner equipped with VA playback capabilities. However, optical sound track negatives (OSTNs) were never meant to be played back, they were meant to be printed for playback. The two main reasons for this are to account for image spread on VA tracks, and exposure issues often referred to as bias and gamma on VD tracks. Current generation image scanning technologies do not currently account for these issues. Due to the demise of film laboratories that can create OSTPs, along with high cost of film printing, there is a need for high quality, economical OSTN playback solutions [2].

Originally driven by the cost factor alone, the Chace Optical Sound Processor (COSP) optical sound track reader was introduced in 1985 for the real-time transfer of OSTNs. It has evolved from that initial version, which featured a rudimentary Comtrack using a 256 pixel CCD camera and a manual threshold control adjusted with a screwdriver into the current version, COSP Xi2k (Chace Optical Sound Processor – eXtended *i*ntelligence2k), which was released by Deluxe in 2014. This integrated hardware and software solution features a sophisticated suite of DSP technologies that control a 4096 pixel, dual-line CMOS camera with a fully integrated and intuitive GUI that offers true 96kHz digital audio transfers of optical sound tracks with 2048 pixel resolution. Using a red LED light source, the COSP Xi2k can be used on any OSTN or OSTP format and has the capability of transferring OSTNs with equivalent or better quality than would be achieved by making an OSTP.

Digital image and audio processing occurs on a proprietary PCIe card that features powerful field-programmable gate arrays (FPGAs), giving it the ability to process complex blocks of data that operate on all 2048 12-bit pixels at the full 96kHz scan rate. This allows the COSP to support all three of its operating modes – Variable Density Mode, Variable Area Edge Detection and Thresholding Mode, and Variable Area Integration and Thresholding Mode – simultaneously, with eight separate 24-bit audio output channels at all times. It can currently be mounted to both MTM and Sondor film dubbers.

Each sound transfer can be optimized in real-time and precise controls and features allow for the elimination of issues that cannot be corrected with traditional track printing. Examples include the elimination of anomalies caused by scratches or cinch marks in VD tracks using a pixel exclusion feature, and cross-modulation distortion and clash compensation for VA tracks.

Figure 12

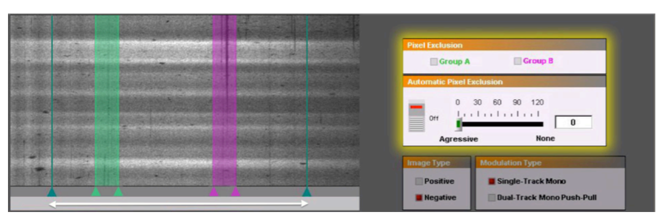


COSP Xi2k featuring a red LED light source.

The cross-modulation distortion compensation feature for VA sound tracks uses a proprietary audio processing algorithm that is designed to remove distortion related to the undersized OSTN image that would have been printed out during the creation of an OSTP. This feature can also be used when playing back OSTPs on the COSP. Many prints were made with the wrong exposures from the sound track, resulting in an incorrect optical transmission density, which can cause distortion. Because the COSP cross-modulation distortion compensation algorithm is not dependent on exposure, it benefits both OSTNs and OSTPs.

Using an active scanning range control, coupled with pixel exclusion zones during VD playback, the COSP can exclude portions of the film, such as those exhibiting perforation buzz from the edge of the sound track and scratched sections, resulting in a better sounding transfer. Additionally, multiple outputs are provided simultaneously, so you can capture the full resolution scan, along with the optimized scan utilizing the pixel exclusion and active scanning range features (figure 13) at the same time.

Figure 13



Portion of COSP Xi software interface showing Pixel Exclusion, noting Active Scanning Range.

Clash compensation is an equally powerful feature, allowing for the interpolation of waveforms to repair distorted and clipped

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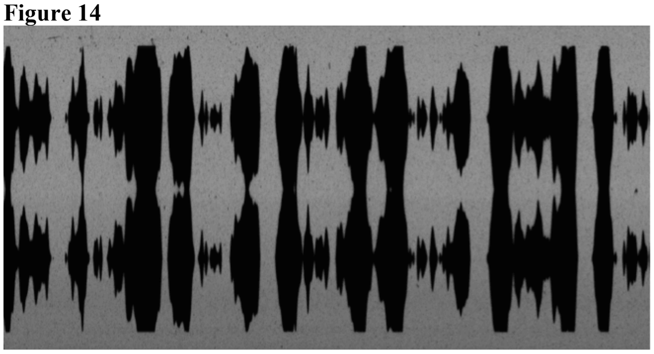
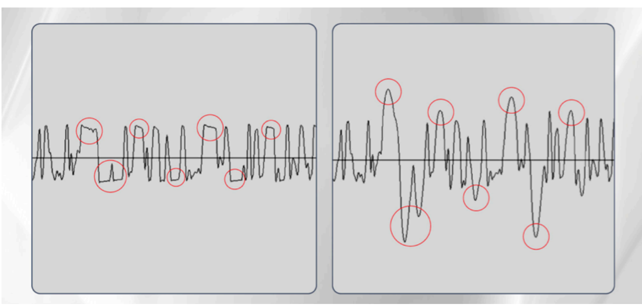
sound regions commonly found in over-modulated optical sound tracks, as shown in figures 14 and 15.

Figure 14



Audio waveforms from a dual bilateral sound track negative with severe clash, as captured by the COSP Xi.

Figure 15



Before and after images for COSP Xi Clash Compensation.

The evolution of the COSP over the past 30 years has introduced a myriad of hardware and software updates culminating in the most comprehensive feature set of any specialized optical sound track scanner on the market. With its extremely high resolution, multiple scanning modes, stable and robust software, and the ability to not only adjust light and image parameters but offer proprietary audio processing algorithms, it is able to transfer every optical sound track format with unrivaled quality. For this reason, Deluxe has used it on millions of feet of optical sound tracks with installations on four separate continents.

Other sound track scanners have recently entered the market with both similar and different approaches to playing back OSTNs and OSTPs. The SoundDirect Laser Scanner uses diffraction to scan VA sound tracks, while the Sondor Resonances uses an adjustable diffused LED light source and features a modular plug-in architecture that allows for processing stages in its audio pipeline. As physical film laboratories continue to disappear around the world, there are sure to be more exciting sound track scanning technologies introduced over time.

Conclusion

With proper identification and mitigation, transfer of optical and magnetic sound tracks exhibiting physical damage and deterioration can be dramatically improved by adopting element preparation techniques and using specialized audio transfer playback systems and technologies. These improved results can be obtained during initial audio digitization, and in the case of optical sound track negatives, alleviate the need for film printing before digitization with better results than traditional film printing while also saving time and money.

Acknowledgements

Robert Heiber, Dave Russell, Joseph Edwards, and Cale Rozett

References

[1] T. Piper and M. Winn, "Combating Vinegar Syndrome in Film Soundtracks," Post, June 1, 2007

[2] R. Heiber, "Considerations for Optical Sound tracks in a Future without Film," Journal of Film Preservation, April 1, 2015

Author Biography

Chris Reynolds currently holds the position of Director of Audio Services for Deluxe in Los Angeles, which includes a specialized audio preservation and archival team focused on preserving, migrating, and restoring audio sound tracks.

He has worked in nearly every aspect of audio operations including technical operations management, optical recordist, transfer and conform engineer, sound supervisor, and re-recording mixer. He is a Full Sail University Alumnus and member of AMIA, AES and SMPTE.

