Contents

Summary Table

Summary table of audio formats. Includes the number of recordings digitized in each format, the number of hours digitized, and the digitizer.

Format	Number	Hours	Digitizer(s)
45 rpm discs	4,032	513.77	Memnon
78 rpm discs (shellac)	34,641	3,703.46	Memnon/IUMDS
Audiocassettes	54,697	64,732.08	Memnon/IUMDS
CD-R	12,190	10,499.66	Memnon/IUMDS
Cylinders	6,643	322.43	IUMDS
Digital Audio Tape (DAT)	8,996	17,671.37	Memnon
Instantaneous discs (lacquer, aluminum)	7,450	1,781.22	IUMDS
LP	38,657	28,066.81	Memnon
Magnabelts	43	8.69	Endpoint Audio
Open reel audio tape	69,047	51,975.28	Memnon/IUMDS
Total	236,396	179,274.77	

I. Introduction

This document provides a summary of the digitization of twelve audio formats by the MDPI project from June 2015-June 2021. Both an external vendor—Sony Memnon—and an internal operation—IU Media Digitization Studios (IUMDS)—supplied digitization services. An overview of the workflows used by Memnon and IUMDS, along with descriptions of key decisions, challenges, and items that were left undone, are included for each format. These items provide a technical summary only. The details of digitization, including complete signal chains, staffing (IUMDS), and condition notes for individual recordings, may be found elsewhere.

II. Global Issues

A. Resolution

All master audio files created were 24 bit, 96kHz. Exceptions were DAT and CD-R, for which native bit depth and resolution was maintained during the transfer from physical carrier to digital file. For example, files from CD-Rs were 16 bit, 44.1kHz.

B. Source for access files

Access files for use in Media Collections Online (IU's public face of the Avalon Media System) were always generated from production master files, not preservation masters. Audio and video preservation master files were defined as comprehensive, complete, and accurate a representation of source recordings as possible. The preservation master is the raw material from the digitization event and it therefore may contain stops and starts from playback, repeated content (caused by skips from a disc, for example,) overlapping content from recordings that change speed, etc. The production master files are processed to present the content as it was intended to be played.

III. Commercial 45 rpm Discs

A. Statistics

Number of 45's digitized by Memnon: 4,032
Number of hours digitized by Memnon: 513.77
Average duration per recording: 7.65

B. Workflows

1. Memnon

Memnon used a 1:1 or 2:1 workflow to digitize 45's. The disc signal chain included a Technics SL-1200MK5 turntable with a Shure SC35C Cartridge, VADLYD MD12 MK3 preamp, and a Mytek 8X192 ADDA A/D converter.

C. Key Decisions

1. Cleaning

All 45's were cleaned using an ultrasonic cleaner before playback. The cleaner was able to handle 20 discs at a time. This system was first developed for the Fonoteca de Lugano in Switzerland, and then customized in Italy to Memnon's needs. Memnon produced their own deionized water for the cleaner and added three tiny drops of a liquid dish soap. Discs with any fiber filler material exposed were not wet-cleaned.

IV. Commercial 78 rpm Shellac Discs

A. Statistics

Number of 78's digitized by Memnon: 34,415
Number of 78's digitized by IUMDS: 226

Total number of 78's digitized: 34,641

Number of hours digitized by Memnon: 3,681.42
Number of hours digitized by IUMDS: 22.04

Total number of hours digitized: 3,703.46

Average duration per recording, Memnon: 6.42 minutes
Average duration per recording, UMDS: 5.85 minutes

Average duration per recording: 6.41 minutes

B. Workflows

1. Memnon

Memnon used a 1:1 workflow to digitize 78's. The disc signal chain included the EMT 948 turntable with a Shure SC35C Cartridge, VADLYD MD12 MK3 preamp, and a Mytek 8X192 ADDA A/D converter. Styli were manufactured by the Expert Stylus Company and were of the following sizes: 3.5 mil elliptical, 3.5 mil conical, 2.8 mil elliptical, and a 2.8 mil conical.

2. IUMDS

The IUMDS workflow was 1:1 for all shellac discs. Digitization took place in the IUMDS studios which were designed for critical listening. Playback machines were Technics SP-15 turntables, fitted with SME 3012-R tonearms and Stanton 500 cartridges. About 30 different styli manufactured by the Expert Stylus Company covering a variety of sizes, both elliptical and conical, ranging from microgroove (0.7) to coarse groove (5.0) were available to choose from.

The disc signal chain included a Timestep T-01 phono preamp that had a gain modification done so that it could output a signal 10 dB higher than its usual operation. Both groove walls were summed together in the analog domain to create a mono file with a typical disc eq curve applied. This file was defined as a preservation master-intermediate file. The preamp also created a "flat" stereo file at the same time, which was used as a preservation master.

C. Key Decisions

1. Signal processing

It was considered beyond the scope of the project to provide a signal processed version that attempted to clean up the noise on the discs. The exception was a standard disc equalization curve that was applied to the preservation master-intermediate to reverse the curve used during recording of the discs.

For discs digitized by Memnon, one of the equalization curve presets available on the VADLYD preamp was assigned ahead of time by SMARTeam staff based on the following decision tree:

Is the disc acoustically (not electrically) recorded? Assume yes if catalog record or other evidence shows recorded before 1925; or if it is on a common acoustic label (Columbia Magic Notes, Gold Band; Victor Patents, Batwing **without VE stamp**); or has other hallmarks of an especially early disc, e.g., no runout groove. Larger-size labels that do not mention electricity are also typically acoustic.

YES → FLAT
NO →
Does the disc have a "VE" stamp showing that it's an early Victor electric?
YES → US MID 30
NO →
Does the disc have a "W" stamp showing that it's an early Columbia electric; or is there evidence that it dates from the mid-1930s or earlier (e.g., earlier date in catalog record, or label is larger in size)?
YES → WESTREX
NO →
Does the disc have a later Columbia label (post-Viva-Tonal) but no "W" stamp, or is a Vocalion recording?
YES → COLUMBIA
NO →
Does the disc have the physical hallmarks of a very late 78 (e.g., "sharp" edge), or does the catalog record list a date in the 1950s or later?
YES → BSI
NO → Early DECCA

The actual equalization of electrically recorded 78's is almost infinitely variable, so the purpose of this decision tree was not to establish the "correct" curve, but to identify the preset *most likely* to come *closest* to the actual curve based on available information about recording-industry practices, while simultaneously meeting the practical demands of a high-throughput process.

2. Stylus selection

For 78's digitized by Memnon, the stylus size was 3.5 mil for acoustic recordings (with equalization curve noted as "FLAT"), 2.8 mil for anything else. The default stylus shape was elliptical, but operators were instructed to substitute a conical stylus for more severely worn grooves.

3. Triage of problem items

Several hundred 78's failed Memnon's process due to problem factors such as cracks. Other discs were held back at the preparation stage when SMARTeam staff identified similar problems through prior inspection. Because the rarity and value of content on 78's is understood to vary greatly from case to case, ranging from comparatively common items to potentially unique ones, MDPI decided in consultation with stakeholders not to have IUMDS attempt to digitize all discs flagged as problematic, but only specific discs that were to be chosen through a follow-up prioritization process. However, no such process was ever implemented, and lack of capacity at IUMDS prior to the end of the project rendered the issue moot.

4. Cleaning

All 78's were cleaned using an ultrasonic cleaner before playback. The cleaner was able to handle 16 discs at a time. This system was first developed for the Fonoteca de Lugano in Switzerland, and then customized in Italy to Memnon's needs. Memnon produced their own deionized water for the cleaner and added three tiny drops of a liquid dish soap. Discs with any fiber filler material exposed were not wet-cleaned.

5. Speed

78's digitized by Memnon were uniformly transferred at 78 rpm, notwithstanding historical variation in actual recording speeds. Discs for which the default speed appeared to be wrong were failed.

6. Disc Imaging

Memnon used a Nikon D810 mounted camera to image disc labels. Discs were placed on an old direct drive turntable with a 19" fluorescent ring light for imaging. Images were cropped to include all of the label and dead-wax to capture any relevant metadata. Images were delivered as .tif files with a resolution of 600 dpi and a bit depth of 24.

IU decided to have one of their own technicians handle the physical media during imaging when a disc was particularly fragile. This applied to lacquer discs on a glass base, and lacquer discs showing delamination or cracking.

In some cases, it was not possible to capture all of the etching and matrix numbers present in the dead-wax. It was decided in cases like this to add in a comment about the issue being present.

D. Challenges

1. Vertically-cut discs

Vertically-cut discs require one side of the stereo channels to be inverted. Therefore, Memnon was initially instructed to fail all such discs they received, which were then to be included among “problem” 78’s supplied to IUMDS. However, Memnon soon (August 2015?) reported they could handle vertically cut 78’s , so from that point on these were supplied to them in specially designated groups.

E. Left Undone

1. 78’s sent to Memnon that were not digitized---557

2. ATM shellacs skipped by mistake—1,474

These were inadvertently missed. The commercial discs in this group are rare and considered to be of very high research value. 440 of them are rare African 78 pressings included in the "Discotheque Internationale de Musique Africaine," mostly in pristine condition, and there are other African items as well (Trek, Gallotone, Nugatone, Jambo, etc.). Also, the UNESCO Collection Universelle; a 78 series published by the Department of Anthropology of the Government of India; some early acoustic 78s from colonial India; a set of 78s in Pashto on a rare Radio Kabul label pressed in the Soviet Union; and miscellaneous Russian, Uzbek, Chinese, Greek, Azorean, Hungarian, Vietnamese, and Native American items.

3. 78’s not sent to Memnon because of damage identified during preparation—we don’t have a number for this. Such discs often had to be simply skipped over due to constraints on both time and sorting space, with no list or tally of quantities being kept.

V. Audiocassette

A. Statistics

Number of tapes digitized by Memnon: 52,907
Number of tapes digitized by IUMDS: 1,790

Total tapes digitized: 54,697

Number of hours digitized by Memnon: 62,671.71
Number of hours digitized by IUMDS: 2,060.37

Total hours digitized: 64,732.08

Average duration per recording, Memnon: 71 minutes
Average duration per recording, IUMDS: 69.06 minutes

Average duration per recording: 71 minutes

B. Workflows

1. Memnon

Memnon used a parallel transfer workflow to digitize eight tapes at the same time using one digitization operator (8:1). Most of the playback decks were Tascam 122 MKIII. Nakamichi MR-1 machines were used as an alternative for problem tapes, such as tapes that may have pressure pads missing, or may otherwise benefit from being attempted on an alternate machine.

2. IUMDS

IUMDS digitized audiocassette tapes that failed the Memnon workflow (see below) using either a 1:1 workflow or a small parallel transfer workflow at 2:1. Tascam 122 MKIII cassette decks were used almost exclusively, although there was a Nakamichi MR-1 available to try on some types of problem tapes.

C. Key Decisions

1. Problem tapes

Tapes with characteristics defined as problematic by MDPI and/or Memnon (see the list below); or tapes that could not be diagnosed, remediated quickly, or digitized by Memnon within their role as a provider of parallel transfer workflows; were sent to IUMDS for digitization.

Tapes containing one or more of the following characteristics were failed by Memnon and re-routed to IUMDS:

- Tapes that broke during attempted playback
- Tape that would not play or stopped playing after initially starting
- Tapes with backwards content
- Tapes recorded at speeds other than 1.875 ips
- Squealing tape
- Tapes perceived to be in generally poor physical condition
- Presence of fungus
- Content recorded at very low levels
- Anything that seemed unusual or odd that could not be immediately diagnosed and remedied
- Pressure pad that needed to be replaced
- No leader on tape—content started immediately at playback and content was lost without the presence of leader tape

2. Azimuth adjustments

Azimuth adjustments based on listening were performed for each audiocassette digitized by Memnon or IUMDS.

3. Dolby

Audiocassettes encoded with Dolby noise reduction are notoriously difficult to digitize. Even if metadata makes clear the presence or absence of Dolby or the type used when it is present, it is often impossible to make it sound as intended during playback. This may be due to a number of factors, including years of degradation. For this reason, IUMDS developed a workflow in which both an undecoded version and a decoded version were captured simultaneously for preservation. The undecoded version, in which Dolby was not used, became the preservation master file. The decoded version, with the Dolby type selected by the engineer who was also manipulating the gain into the Dolby circuit to find the 'best sound,' was designated a preservation master-intermediate. A post on the MDPI blog provides more information on the Dolby workflow.

D. Challenges

1. Dolby (see above)

2. Type III

We encountered a handful of type III cassettes at MDPI. These were transferred in our Nakamichi MR-1 deck where tape type can be selected manually. Type III cassettes have Type I

notches on the top edge of the shell, but use Type II playback EQ. If they were transferred in a Tascam 122 MKIII, for example, they would typically be played back with Type I EQ, providing an inaccurate representation of the intended signal.

3. Non-functioning azimuth screw

Azimuth screws were not originally designed to be adjusted for every audiocassette that is played in a given cassette deck. These screws were designed to be set and aligned only occasionally, and it was assumed that a deck used to record a tape would also be used for playback. This is not the case in the world of audio preservation, where we digitize large collections of tapes recorded with many different types of equipment and settings. In audio preservation we must adjust azimuth for every tape to ensure we are capturing as much of the intended signal as possible. This results in wear to the threads of the azimuth screw and mounting plate and it becomes stripped. When this happens, azimuth can no longer be adjusted. To solve this problem, MDPI engaged Jeff Brown of Clair Audia in Durham, NC to make repairs. He replaced the old azimuth screw with a new socket head screw made of much harder material (Class 12.9 types) that should never wear out. In addition, he also cut another millimeter or two of additional threads into the bushing that would give more security and durability to this repair.

E. Left Undone

1. Dolby tapes

An estimated 3,000 tapes with Dolby NR were digitized by Memnon before IUMDS had recognized the problem, evaluated the options, and put its new Dolby workflow in place. These transfers could be improved in many cases by re-digitizing using the new workflow.

2. Failed tapes

Although IUMDS digitized a large number of tapes that failed the Memnon process, there remain a substantial number yet to be tackled. We estimate that there are 3,000 cassettes in this category.

3. Audiocassettes that are not compact cassettes

MDPI did not digitize microcassettes or minicassettes. We estimate that IU holds around 175 microcassettes and 12 minicassettes.

VI. CD-R

A. Statistics

Number of CD-Rs transferred by Memnon: 11,850
Number of CD-Rs transferred by IUMDS: 340

Total CD-Rs transferred: 12,190

Number of hours transferred by Memnon: 10,213.14
Number of hours transferred by IUMDS: 286.52

Total hours transferred: 10,499.66

Average duration per recording, Memnon: 51.7 minutes
Average duration per recording, IUMDS: 51.68

Average duration per recording: 50.56 minutes

B. Workflows

1. Memnon

Memnon used NOA CDLector software to transfer CD-Rs. The CD drives used were Samsung - SH-D163 internal SATA drives mounted in LC Power - EH-525B-PS external SATA/IDE boxes.

One file per CD-R was created to accurately represent the source object. Memnon delivered a BWF preservation master and a BWF production master. In addition, Memnon delivered:

- The usual output xml file which for this format carried the digitization comment “CD Read Errors” whenever they were present
- An error log listing the CD Read Errors and their location (text file)
- A wmf file (graphical representation of errors)
- A cue file that, when associated with an audio player, will allow the user to navigate within the file. The cue file carries time offsets for markers

2. IUMDS

IUMDS primarily used Exact Audio Copy (EAC) to transfer CD-Rs, with IsoBuster as a second option in cases for which EAC was not suitable. Multiple drive types were used to secure the best results from problem discs, including the PLDS DVD±RW drives mounted by default in university workstations and a Hitachi-LG Data Storage USB drive, model GP65NB60. Disc contents were ripped track by track and concatenated into deliverable files using a custom

application written in MATLAB. For cases in which EAC failed to rip a track successfully in Secure Mode, we made and retained multiple transfers. An averaged version of the track was then generated in which each sample is the median average calculated from the values for that sample in all available rips of the track.

One file was created per CD-R. IUMDS delivered a WAV preservation master and a WAV preservation master-intermediate file. In cases of averaging, the preservation master contains all rips of all tracks, while the preservation master-intermediate file contains a single averaged version of each track. In addition, IUMDS delivered:

- A report of any detected discrepancies between the disc Table of Contents and the ripped tracks, plus any Exact Audio Copy logs (text file)
- Two cue files for the preservation master and preservation master-intermediate files that, when associated with an audio player, will allow the user to navigate within the files. These cue files carry time offsets for tracks. Track titles in the preservation master-intermediate file indicate any track associated with errors. Track titles in the preservation master indicate the drive used and the rip attempt number. Any missing tracks are noted as such and included in the sequence with a duration of zero.

C. Key Decisions

1. Problem CD-Rs

CD-Rs that failed the Memnon workflow were routed to IUMDS.

CD-R tracks that then repeatedly failed a Secure Mode rip in Exact Audio Copy were subjected to a multiple-rip averaging process.

CD-R tracks that could not be ripped with Exact Audio Copy were ripped with IsoBuster when possible.

2. Hybrid Discs

With CD Extra and Mixed Mode discs, Memnon transferred the audio signal in CDA format but ignored tracks containing data.

3. Partial Rips

If only part of the content of an audio CD-R could be extracted by IUMDS, that part was still submitted, with missing tracks or parts of tracks noted in accompanying metadata.

4. Cleaning

Memnon did a visual inspection, and if a disc was detected to be dirty, it was cleaned with a light wipe using a microfiber lens cleaning cloth in straight motions from center to outside of the disc. This was not a circular motion.

D. Challenges

1. Audio CD-Rs that had not been closed after burning.

These are ordinarily “invisible” to a Windows operating system because they lack the Table of Contents which is used to generate CDA stub files. The content of these discs was instead extracted using IsoBuster.

2. CD-Rs that could not be ripped without errors in Secure Mode using Exact Audio Copy

In Secure Mode, Exact Audio Copy confirms that each sample can be read twice identically from the disc during a single rip on one drive. For any track where this can’t be done successfully, IUMDS tried to improve reliability by averaging the sample values obtained by multiple rips on multiple drives.

E. Left Undone

1. CD-Rs formatted as data discs, regardless of whether the data consists of audio files or something else. These were deemed out of scope and were excluded at various points (before submission, during preparation, or during an extraction attempt).

2. A number of discs could not be ripped because neither a Windows operating system nor IsoBuster recognized any content in multiple drives or because no meaningful content could be accessed. Sometimes discs were reported as “blank” despite having visible content burned onto them. In other cases, drives didn’t recognize that a disc was physically present at all. In yet other cases, an audio CD Table of Contents was accessible but no actual content could be extracted from the audio track.

3. One disc was not ripped because it cracked in the drive at Memnon. Some other discs were intercepted as unplayable at the preparation stage if the foil was visibly delaminating.

VII. Cylinder

A. Statistics

Number of cylinders digitized by IUMDS: 6,643
Number of hours digitized: 322.43
Average duration per recording: 2.91 minutes

B. Workflows

The IUMDS workflow was 1:1,and focused on brown wax cylinders held at the Archives of Traditional Music (ATM) in IU Libraries. The cylinders, dating from 1893 into the 1930s, were digitized as part of a project funded largely by the National Endowment for the Humanities. IUMDS acquired an Endpoint Audio Labs cylinder machine, which has many modern features to allow the audio engineer to capture a more accurate representation of the content than was previously possible. This machine was invented by Nick Bergh.

A laser mounted below the playback stylus took measurements of the surface of the cylinder at different points around the circumference, providing a way to "center" the cylinder on the playback mandrel with precision according to the shape of each one. This was necessary because cylinders, especially brown wax, can become misshapen over time resulting in wow and flutter defects in the audio during playback. The Endpoint machine also has a high-powered microscope for inspecting the individual grooves of a cylinder. This is very helpful when developing strategies for playing cylinders with tracking issues, locked grooves, and cracks.

For playback, a Shure V15Vx cartridge was used with a choice of 7 different styli, ranging from 14 x 3.7 Elliptical Full Conical Radius to 6 mil Elliptical and Conical. The polarity of the Shure cartridge was reversed to account for the cylinders' vertical groove configuration. Both groove walls were summed together using the Timestep T-01 preamp to create a mono file, defined as a preservation master-intermediate file. The preamp also simultaneous output a "flat" stereo file, which was used as a preservation master.

C. Key Decisions

1. Testing

Indiana University extensively tested three stylus-based machines before deciding on the Endpoint Cylinder machine. During testing, each machine played the same six cylinders to provide common ground from which to compare performance. Four of those cylinders contained the technical characteristics of most of our collections, while two were modern cylinders with test tones and frequency sweeps. Unmodulated sections of the test cylinders

were used to measure machine noise and rumble, and specific test tones were used to measure wow and flutter. Bergh's machine performed significantly better in these areas and provided more overall clarity to the test material.

2. Wow and flutter compensation

Problems caused by wow and flutter often exceeded the amount for which we were able to compensate during physical playback. To account for this, the machine outputs a 440 Hz reference tone that is modulated by the cylinder surface distance readings taken by the laser during playback. This reference tone can be used in software such as Capstan, to remove any further wow and flutter from the cylinder transfer.

3. File types and roles for cylinder digitization –

Preservation Master – This is the primary surrogate for long-term preservation. It carries the raw material from the transfer of the cylinder and is complete, un-altered, un-equalized, and un-edited.

Preservation Master Reference Tone – a mono file with 440 Hz tone that is an exact match of the Preservation Master. Used for correcting time-based instabilities from playback of the cylinder.

Preservation Master-Intermediate- A faithful representation of the source recording. It is considered a co-master and a valid stand in for the preservation master. It is mono-summed, top & tailed, un-equalized. Repeated sections from locked grooves are removed, and reversed content is in the forward direction.

Preservation Master-Intermediate Reference Tone - a mono file with a 440 Hz tone that is an exact match of the Preservation Master-Intermediate. Edits were made to both of these files (the *Int* and *IntRef)* at the same time by editing them as a single stereo file and saving as separate mono files.

Production Master – This file type was used to generate all further derivatives. It is a representation of the source cylinder recording that was signal processed for presentation to end-users. Signal processed Production Master files were created to provide a more listenable version of the content, primarily by decreasing the amount of surface noise in the file. Isotope RX6 plugins were used, as well as the Fab Filter Pro Q2 plugin for EQ. This signal processing was done quickly, applying pre-existing templates and tweaking as needed. It was not intended to be a full restoration.

D. Challenges

For each cylinder, the engineer would look for chips, cracks, bumps, holes, or any other physical characteristics that could damage the machine, or the cylinder even further when attempting to play. Cylinders that were too damaged to play were noted in the POD, and set aside for a possible optical transfer.

Cylinders that were out of round, contained grooves in the reverse direction, or had grooves that fell right off the edge of the cylinder were captured by taking the mandrel off and setting it in the reverse direction. This allowed the engineer to play a locked groove from both directions, capturing the backwards content, as well as the grooves cut into the outermost edges. This ensured that we could digitize every groove of a cylinder.

There were no standards for speed with field cylinders. Finding the correct playback speed was very challenging, and often varied from cylinder to cylinder. This required knowledge of the ethnomusicologist who did the recording as well as where and when it was made. It was helpful to consult the notes from the IU cylinder transfer project in the 1980's to determine if the speed they used back then was correct.

Field-recorded cylinders come with a host of tracking problems. The grooves are inherently very shallow, which makes it easy for a stylus to "skate" along the top of the cylinder with any surface bump, chip, warp, or oddly cut groove. Cracks in the cylinder itself also can send a stylus out of the groove. Playing back a cylinder at half speed resolved many of these issues and enabled us to play the cylinders smoothly. When this was necessary, the engineers would over-sample at 192kHz so that the half speed playback would sound correct when played at 96kHz.

Engineers were very careful when handling a cracked cylinder. There was always a chance that handling a damaged cylinder or attempting to play it would make the crack worse or cause it to break completely. If there were any doubts about the stability of the cylinder, the engineers did not attempt to play it, and set it aside for a possible optical transfer.

E. Left Undone

An additional 470 cylinders were broken or too badly cracked to play with a stylus. Much of the content on these broken and cracked cylinders can be recovered using some type of non-contact, optical methodology. At this time, there are two options available to us:

1. Use the IRENE system that has been commercialized by the Northeast Document Conservation Center (NEDCC). IRENE scans the surface of the cylinder, producing high-resolution images.

2. Add an addition to our stylus playback machine that uses a laser to trace the grooves and play the content optically in real time.

VIII. Digital Audio Tape (DAT)

A. Statistics

Number of tapes transferred by Memnon: 8,996
Number of hours transferred by Memnon: 17,671.37
Average duration per recording: 117.86 minutes

B. Workflows

1. Memnon

Memnon used the NOA MediaLector system to transfer DATs. This application collects error correction and concealment data for each transfer. Eight Sony PCM 7040 playback machines were used in parallel to do the transfers.

C. Key Decisions

The music library recorded two DATs for most programs. IUMDS developed a restoration workflow to deal with the problem described below in section D, within which staff created a compilation file that featured the best of both copies. This work was undertaken by IUMDS after the transfer of this format was completed by Memnon.

D. Challenges

1. Approximately 30% of the DAT files from the digitization of tapes held by the music library exhibited significant glitches, noise bursts, clicks and other problems that are introduced when the error correction circuitry is no longer able to correct the errors encountered. These problems result in loss of content as they obscure or replace the intended audio.

E. Left Undone

Thousands of files from the transfer of DATs contain enough errors to make them difficult or, in some cases, impossible to use. These may benefit from the restoration workflow described below. They may also benefit from re-transfer on a different brand of playback machine or from procedures that involve re-aligning the playback machine transport to better match the data on tape. This technique is used by some practitioners to reduce the number of errors during playback.

F. DAT Restoration Project

1. Statistics

Number of DATs whose files were edited and compiled: 638

2. Workflow

The objective of the DAT restoration project was to identify files with errors from the content recorded on two DATs, select the best-sounding (usually most error-free) parts of both in order to construct a production master file that provided as much usable content as possible. In some cases, one file will have damaged audio at a specific location while its duplicate will be error-free. In others, both files may contain damaged audio at the same place. In this situation, the best-sounding content was selected unless both were equally unusable.

YAML was used for project metadata. Engineers entered metadata into a spreadsheet. This metadata was converted into a YAML document by the IUMDS processing and QC specialist.

IX. Instantaneous Discs

A. Statistics

Number of instantaneous (lacquer and aluminum) discs digitized by IUMDS: 7,450 (6,145 lacquers and 1,305 aluminums)

Number of hours digitized: 1,781.36 (1,592.86 for lacquer and 188.5 for aluminums)

Average duration per recording: 14.34 minutes (8.67 minutes for aluminum/15.55 minutes for lacquers)

B. Workflows

1. IUMDS

The IUMDS workflow was 1:1 for all lacquer, aluminum, and other instantaneous discs. Digitization took place in the IUMDS studios designed for critical listening. Playback machines were Technics SP-15 turntables, fitted with SME 3012-R tonearms and Stanton 500 cartridges.

Measuring the top and bottom of the groove provided a recommended stylus size, which was used as a place to begin the process of selecting a stylus. About 30 different styli manufactured by the Expert Stylus Company covering a variety of sizes, both elliptical and conical, ranging from microgroove (0.7) to coarse groove (5.0) were available to choose from.

The disc signal chain included a Timestep T-01 phono preamp that had a gain modification done so that it could output a signal 10 dB higher than in its usual operation. Both groove walls were summed together in the analog domain to create a mono file with a typical disc eq curve applied. This file was defined as a preservation master-intermediate file. The preamp also created a “flat” stereo file at the same time, which was used as a preservation master.

The Baerwald-Lofgren alignment calculator was used to determine the correct horizontal tracking angle (zenith) for each disc.

C. Key Decisions

1. Digitizer

The decision was made during project planning that all instantaneous discs (primarily lacquers and aluminums) would be digitized by IUMDS. Audio engineers were hired for this work.

2. Signal processing

It was considered beyond the scope of the project to provide a signal processed version that attempted to clean up the noise on the discs. The exception was a standard disc equalization curve that was applied to the preservation master-intermediate to reverse the curve used during recording of the discs.

3. Unmodulated grooves

Some discs contained grooves on one side that were unmodulated (i.e., no recorded content). The engineer listened to the entire side to confirm that there was no content but did not retain audio files. No digital provenance files were created for unmodulated sides. The engineer made a note in the general object comments field in the POD that the side contained unmodulated grooves/no content.

D. Challenges

Discs with warps, chips, severe delamination, or large divots, that would prevent a stylus from tracking cleanly were digitized as much as possible, leaving the damaged areas to be optically scanned at a later date if desired. Metadata comments for these types of files indicate how much of the content was recovered, (ex. 50% or 90% of content was digitized).

E. Left Undone

All instantaneous discs held by IU were digitized with the exception of a few that were evaluated by IU unit staff as having very low value.

X. LP

A. Statistics

Number of LPs digitized by Memnon: 38,565

Number of hours digitized by Memnon: 28,066.81

Average duration per recording: 43.67minutes

B. Workflows

1. Memnon

Memnon used a 4:1 parallel transfer workflow to digitize LPs. The disc signal chain included a Technics SL-1200MK5 turntable, Shure M44-7 cartridge, VADLYD MD12 MK3 preamp, and a Mytek 8X192 ADDA A/D converter.

C. Key Decisions

1. Value

LPs were considered a relatively low priority by nearly all of the IU stakeholders with holdings in this format. This value assessment impacted other decisions, including allocation of QC resources and handling of discs with problems (see section on stylus jumps, below.)

2. Mono LPs

Representatives of IUMDS, the MDPI SMARTeam, and the Music Library met to discuss issues with mono LPs. They decided to maintain ‘stereo’ files for the access copies, for the reasons listed below.

- It can be difficult to identify mono LPs. With stereo access files, we do not need to worry about accuracy problems, that is, misidentifying stereo LPs as mono and sending them through a mono process
- If the LP is mono, the access file is actually dual channel mono, which is how a music access system would present a one channel file
- SMART would not have to separate stereo and mono LPs during the prep stage

Note that the preservation master file was a two-channel file in order to preserve both sides of the groove. One side may contain damage in places where the other is fine.

Providing a mono file would have created several advantages, including a lowering of the noise floor and a reduction in noise caused by grooves damaged by scratches and other things.

3. Non-RIAA curve LPs

The Vadlyd MD12 MK4 preamp used by Memnon had four microgroove settings: ffrr LP 1953, CCIR, NAB, and RIAA. The SMARTeam used the following decision tree to assign an equalization curve to each disc supplied to Memnon for digitization.

Was it mastered in 1956 or later, or on RCA Victor in 1953 or later? YES → RIAA. No →

Is it on Decca, HMV, or Columbia (UK)? YES → ffrr LP 1953. No →

Is it on a European label? YES → CCIR. No →

Is it on Columbia (US)? YES → mark as Other, put "NAB + 80 Hz bass cut" in Note to be included in shipping manifest. No →

NAB

Soviet LPs were also routinely digitized using the CCIR curve, even when mastered in or after 1956. The SMARTeam obtained information about date and origin variously from the objects themselves, from catalog records, or from other discographical or labelographical resources.

4. Stylus selection

For discs mastered in or after 1956, a .0007 elliptical stylus was used. For earlier LPs, a .0011 elliptical stylus was used.

5. Re-digitizing LPs with problems

At a meeting on October 7, 2015, representatives from the ATM, Music Library, Memnon, and IUMDS decided to take no action when stylus jumps were discovered in the files for the following reasons:

- Stylus jumps so far occurred on less than 1% of LP sides
- This format is low priority for the ATM and Music Library
- For IUMDS to re-digitize would take significant time and resources and would take away resources for more valuable formats
- Success rate for working through problematic skips might be relatively low
- We can re-digitize at the time that a researcher requests an item that has this problem

This policy was later extended to cover all problems discovered on LPs. In contrast to other formats, IUMDS did not re-digitize LPs for any reason, due to the issues discussed above.

6. All LPs were cleaned using an ultrasonic cleaner before playback. The cleaner was able to handle 20 discs at a time. This system was first developed for the Fonoteca de Lugano in Switzerland, and then customized in Italy to Memnon's needs. Memnon produced their own deionized water for the cleaner and added three tiny drops of a liquid dish soap.

D. Challenges

1. University legal counsel advised that MDPI should not digitize content on LP that had been reissued commercially on audio CD. Determining this on an item-by-item basis was found to be unfeasible. However, preparatory work at the units did prioritize less-common labels (e.g., via Music Library picklists which unit staff organized by groupings of labels) and avoided mainstream commercial releases (e.g., excluding discs such as "Abbey Road" during preparation on a case-by-case basis).

2. A series of "Special Edition" discs held by the ATM contained many sides with multiple locked grooves for use by radio DJs. These were initially failed by Memnon but were deemed to be of higher-than-average value. In February 2016 we began submitting these discs (or resubmitting them if they had already been failed) to Memnon in separate batches to be digitized using a special workflow in which engineers were permitted to advance the stylus manually past a locked groove.

E. Left Undone

It was never MDPI's objective to digitize all LPs held by IU. We estimate that around 140,000 LPs were not digitized.

XI. Magnabelts

A. Statistics

Total belts digitized: 43
Total hours digitized: 8.69
Average duration per belt: 12.13 minutes

B. Workflows

1. Endpoint Audio

An outside vendor—Endpoint Audio—was used to digitize the Magnabelts. The playback device was the Endpoint Audio Labs cylinder machine.

2. Challenges

The information below is from our vendor, Nicholas Bergh, at Endpoint Audio Labs:

The track is smaller than a stereo cassette track with only a fraction of the guard band between tracks. Also, since the recording is a helix, any time someone re-records over a section without bulk erasing the belt, they are not able to perfectly sync the erasing of the new track with the location of the old track. As a result, there is often low-level audio in the guard band area from a previous recording in that area. Furthermore, the small track requires high precision to maintain sync, but the original recorders had occasional belt wander. This is especially an issue in the first 30 seconds or so of most Magnabelts when the belt is still settling in the recorder. This beginning 30 seconds is where one is most likely to hear faint audio from the neighboring track or previous recording. According to the IBM service manual, some belt drift is inherent in the system design, so this is hard to avoid.

These belts are generally lower in quality than the last set of belts because they were 1) mostly recorded on a cheaper portable machine with more mic/electronics distortion and 2) were mostly recorded on a plane with high background noise. The background noise probably also contributed to him overloading the mic.

The portable machines used a 4" wide belt instead of a 6" wide belt. Additional problems occur when one uses a 4" belt in a 6" machine. The machines are aligned so that there is some intentional belt wander to the flange so that the belt seats itself quickly. However, when the belt is 4" on a 6" mandrel, it has 2 inches to wander before the flange is reached so the LPI is not accurate or consistent on the belt. This poor tracking can be found in belt 40000003739747 where you will hear occasional audio in the background from mistracking. This transfer is the best possible for this problem.

XII. Open Reel Audio Tape

A. Statistics

Number of tapes digitized by Memnon: 65,905
Number of tapes digitized by IUMDS: 3,142

Total tapes digitized: 69,047

Number of hours digitized by Memnon: 48,720.97
Number of hours digitized by IUMDS: 3,254.3

Total hours digitized: 51,975.25

Average duration per recording: 45.17 minutes
Average duration per recording, Memnon: 44.36 minutes
Average duration per recording, IUMDS: 62.14 minutes

B. Workflows

1. Memnon

Memnon used a parallel transfer workflow to digitize four tapes at the same time using one digitization operator. There were two 4:1 setups in the same room, with one operator responsible for the four tape machines on the east side of the room and the other responsible for the four machines on the west side of the room. Because these two operations were located in the same physical space, the operators were required to take turns monitoring the tapes during digitization. Therefore, the percentage of any given tape that was audible during digitization was similar to what would be characteristic of a larger 8:1 workflow. Playback machines were Studer A807's. Tapes were digitized from the physical beginning to the physical end of the tape, regardless of whether content extended to the end or finished with blank tape left. Therefore, there may be long stretches of blank tape that were digitized and appear at the end of the file.

Thermal Treatment (baking):

Items exhibiting binder hydrolysis were placed into a sidechain process wherein the items were baked prior to digitization.

- Items were baked for 12 hours in a low temperature dehydrator – (Memmert IF 260 Incubator)
- Tapes were baked only once.

Inspection and diagnosis

The Memnon open reel audio tape workflow benefitted greatly from sorting tapes by technical characteristic or preservation problem prior to digitization. This process involved playing tapes to identify track configuration, playback speed, and tape repair/remediation requirements. IU SMART conducted playback inspections at the start of the project but was not able to keep up, leading to a bottleneck in the Memnon workflow. Memnon took over this work and diagnosed 19,077 open reel tapes.

2. IUMDS

IUMDS digitized the open reel tapes that failed the Memnon workflow (see below). The IUMDS workflow was 1:1, that is, one audio engineer digitized one tape at a time. Digitization took place in an IUMDS studio designed for critical listening. Playback machines were Studer A810's. Advanced diagnostic and restoration skills were available for these items from the MDPI AV Specialist and the audio preservation engineering team.

Tapes with speed and/or configuration changes were played back and digitized with the intended playback settings to create a file that was an accurate representation of the tape content. Preservation master files contain the raw transfer including speed changes, using an overlap of content at the specific location of the change at both speeds. Production master files were edited to remove incorrect speeds and serve as a listenable version of the content.

C. Key Decisions

1. Problem tapes

Tapes with characteristics defined as problematic by MDPI and/or Memnon (see the list below); or tapes that could not be diagnosed, remediated quickly, or digitized by Memnon within their role as a provider of parallel transfer workflows; were sent to IUMDS for digitization.

For example, all open reel audio tapes that contained content recorded at multiple speeds or with multiple track configurations were automatically assigned to IUMDS for 1:1 digitization, if this was known in advance. If tapes with these characteristics were discovered by Memnon, they were failed and were sent back to IU so that they could be re-routed to IUMDS.

Further, tapes containing one or more of the following characteristics were failed by Memnon and re-routed to IUMDS:

- Tapes that broke twice during attempted playback—Memnon repaired the first break but failed the tape after the second break
- Squealing tape that did not respond to initial baking or was squealing for a reason other than sticky shed syndrome
- Perceived major signal anomalies such as severe crosstalk or severe wow and flutter

- Perceived generally poor physical condition
- Presence of fungus
- Content recorded at very low levels
- Anything that seemed unusual or odd that could not be immediately diagnosed and remedied

Tapes recorded at speeds slower than 3.75 ips were digitized by both Memnon and IUMDS.

2. Azimuth adjustments

Azimuth adjustments based on listening were performed for each tape digitized by Memnon or IUMDS.

3. Reverse playback

Reverse playback was *not* used by either Memnon or IUMDS. For example, ½ track tapes recorded in both directions (containing two mono tracks of discrete content) were digitized by playing each track in the forwards direction, which required two playback attempts rather than one. The exception is when the configuration of the tape head prevented forward playback, such as track 2 in a ¼ track tape that had been recorded in the forward direction. In these cases, reverse playback is the only way to play the content.

4. Cleaning items with fungus

Items identified with mold were cleaned prior to diagnosis or digitization. Hand cleaning was performed on a case per case basis using IU's encapsulated HEPA filtration enclosure and dust free pellon material. The enclosure has iris ports for the technician's hands and a HEPA filter and vacuum to remove airborne mold spores. The enclosed tape machine is dedicated to mold removal work. The dry wipe process removes most of the fungal growth and, as a result, it is no longer visible to the naked eye. It is likely that some spores remain. A recent study demonstrates that neither wet nor dry cleaning procedures remove 100% of mold spores.

Tapes were only cleaned once using the following procedure:

- Separate the items with mold from those without issues
- Perform a visual inspection of the item to determine if the mold appears active or dormant and to document the extent of the fungal growth
- If the mold is dormant, use an archival vacuum to clean the tape pack and tape box

The tape was dry wiped using pellon while slow winding it on a tape machine enclosed in a plexiglass box.

Cleaned tapes were re-housed in new tape boxes.

5. Imaging tape boxes holding moldy tapes

Affected tape boxes were imaged using the camera and copy-stand arrangement also used for imaging of commercial 78 rpm shellac discs.

Memnon used a Nikon D810 mounted camera to photograph flattened tape boxes. Tape boxes were placed on a Kaiser copy-stand with a 19" fluorescent ring light for imaging. Images were cropped to include all of the surface. Images were delivered as .tif files with a resolution of 600 dpi and a bit depth of 24.

D. Challenges

1. Slow speed tapes, defined as recorded at 1.875 ips or 0.9375 ips, were digitized by IUMDS. They were played on a 'slow-speed' Revox B-77 tape machine that enabled quarter-track and half-track tapes at these speeds to be digitized.

There are no good options for playing full track tapes recorded at slow speeds as there are no professional tape machines that can handle this configuration. The work-around chosen by IUMDS is to capture both channels of a half-track playback head using the Revox machine and then choose one of the channels for the production master. The preservation master retains the two channels from digitization. This choice was based partly on comparative listening to a Revox half track, Studer full track with resampling, and Revox with both half tracks combining to one channel using an azimuth correction tool: the files for the Revox half track sounded better than the other two options with more high-frequency information and greater clarity than the others.

Quarter track slow speed was done with a quarter track head on the Revox, but since that machine malfunctioned, the process shifted to oversampling at 192 kHz the quarter track slow speed tapes on the Studer quarter track at 3.75 ips, which resulted in 1.875 ips equivalent files. Due to obsolescence issues, it has proven difficult to repair or replace the Revox quarter track head.

E. Left Undone

1. 'Timecode' tapes

IU holds about 1,300 open reel tapes that were apparently recorded simultaneously with motion picture film. These audio tapes contain 'wild sound' for the correlated films. Several mechanisms and/or systems were used to synchronize audio tapes with film, the most common of which was known as neo-pilot tone. IU holds primarily neo-pilot tone, although there are also tapes that use other sync systems.

2. Failed tapes

Although IUMDS digitized a large number of tapes that failed the Memnon process, there remain a substantial number yet to be tackled.

3. Non-1/4"

Most open reel audio tape in archival collections is ¼” in width. IU holds just a few tapes—about 92—that are greater than ¼” wide. This includes ½”, 1”, and 2” tape.