Mind Your Disc!

Retrieving and archiving audio information stored in MiniDisc

A Thesis

Presented to

The Faculty of the Moving Image Archiving and Preservation Program

of the Department of Cinema Studies

New York University

In Partial Fulfillment

of the Requirements for the Degree of Master of Arts

By

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May, 2021

Abstract

Archiving and preserving born-digital media formats have been a big challenge to archivists. MiniDisc (MD) – an obsolete born-digital optical media format - brings no less perplexities. MiniDisc media and MiniDisc recorder-players were launched by Sony in 1992. In the late 1990s and early 2000s, MiniDisc became popular among consumer and professional markets, including many cultural institutions. However, Sony discontinued manufacturing and providing support to MiniDisc in 2013. Due to MiniDisc's relatively short life, highly proprietary nature and heavy hardware and software dependencies, systematic research on its technical mechanism and documentation of content retrieval and archiving workflows are in scarcity. This raises an alarm to cultural institutions and audiovisual (AV) archivists.

This thesis first presents a historical and technical investigation into MiniDisc. It then, based on interviews with media practitioners and archivists, discusses the usage of MiniDisc among cultural institutions and explores existing workflows of retrieving and archiving audio contents stored in MiniDisc. Following this, this thesis documents different methods of retrieving and archiving MiniDisc contents based on the author's own lab experiments. Different models of MiniDisc players, proprietary software and open-source Python code-based tools are employed. Discussions and follow-along instructions of different MiniDisc content retrieval and archival approaches are also documented.

Acknowledgement

I owe my greatest gratitude to those have generously and wisely guided me, inspired me and helped me during the MIAP intellectual journey and the thesis project:

- MIAP faculty, staff members and the wonderful team of adjunct professors who helped me set foot on a solid MIAP knowledge ground;
- My thesis advisor Benjamin Turkus who always nudged me to go even an inch further (and further, especially in exploring open-source tools and codes);
- My dearest cohort-mates (together we went through the once-in-a-century pandemic!);
- My internship advisors who gave me the liberty to develop my digital skills through trials-and-errors – Kelly Haydon and Sophie Glidden-Lyon;
- Audiovisual professionals who unreservedly provided me valuable information about MiniDisc and more – Andy Lanset, Eddy Colloton, Geoff Willard, Gosha Shtasel, Isaac Hart, Laura Russak, Mary Kidd, Nicole Martin;
- The MiniDisc communities on Facebook– folks who enthusiastically share their experience working with and repairing MiniDisc;
- Linux-minidisc developers – devoted engineers who brilliantly developed scripts and appliances (through reverse-engineering the original proprietary software) for muggles to manage MiniDisc contents in a more flexible and hustle-free way;
- My husband Po-Sheng who ruthlessly pushed me to start coding, GitHub-ing and fearlessly diving into the digital realm.

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Chapter One: Introduction

2019 marks the 40th anniversary of Walkman – a flagship invention by Sony - one of the world's leading electronic manufacturers. "Walkman" is a registered trademark of Sony, but later it undoubtedly becomes a generic term referring to a large series of consumer-market-oriented portable media players. To celebrate this landmark, Sony released a 1-minute advertisement featuring different generations of signature Walkmans that accommodate different Sony-led media formats, namely audio-cassette Walkman, CD (compact disc) Walkman – aka "Discman", MiniDisc Walkman, and MP3 Walkman.[1] While most of these media formats enjoy four decades of lifespan in the market,[2] MiniDisc is an exception. MiniDisc, also called MD, was launched to the mass market in 1992. But in 2013, the inventor of MiniDisc – Sony discontinued manufacturing of MiniDisc players, marking the obsolete status of this media format.

MiniDisc, as a media format, is an optical-disc-based magneto-optical recording media that writes and plays audio information in a born-digital form. MiniDisc appears in two forms: pre-recorded commercial disc and recordable-rewritable disc. Accompanying the launch of MiniDisc as a media format were MiniDisc recorder-players in portable Walkman and professional deck fashions. In 1992, MiniDisc was promoted by Sony as a flagship product to surpass the CD in the music industry: MiniDisc was an industrial advancement armed with the CD-quality and cassette (editability) convenience.[3] It was regarded a technology that features

[1] "SONY WALKMAN® 40TH ANNIVERSARY MOVIE," SonyHongKong YouTube Channel, July 23, 2019, https://youtu.be/kFK6P8xCKMc

[2] According to Museum of Obsolete Media, 1/8 inch compact cassette was invented in the 1960s and becomes obsolete in the 2000s. CD was invented in the early 1980s and is still being used. MP3 was released in the early 1990s and is still widely used. See "Audio Format Timeline," Museum of Obsolete Media, https://obsoletemedia.org/audio/

[3] Joey Faulkner, "MiniDisc, the Forgotten Media," *The Guardian*, Sep 24, 2012, https://www.theguardian.com/music/musicblog/2012/sep/24/sony-minidisc-20-years.

"editing at your fingertips".[4] Media reviewer Nilay Patel once wrote, "in 1992, when the quirky new music format was introduced, Sony could do no wrong in consumer electronics."[5] However, MiniDisc was later regarded a format that failed in the professional and mass consumer markets due to factors such as over-pricing, fiddly recording mechanism, and the lack of pre-recorded commercial albums available in the market.[6] What's more, the rapid advancement and prevalence of flash-drive based MP3 players and iPods since the late 1990s further caused the demise of MiniDisc.

Nevertheless, MiniDisc at its height of market share, was adored by individual and organizational consumers around the world. In the early 1990s, there were over a thousand commercial titles released in pre-recorded MiniDiscs. In 1993, over 50,000 units of MiniDiscs were sold in the United States. In the early 2000s, though pre-recorded MiniDisc albums almost disappeared from the market, blank MiniDisc, which provide recordable and rewritable flexibility to consumers, kept escalating.[7] Among the huge amount of MiniDisc users out of the birthplace of this media – Japan, were not only general music lovers, but also memory institutions and media organizations in Europe and North America. Collections of MiniDisc, which used to be an important medium to record audio information (e.g. oral history, media interview), were found in prominent cultural institutions such as The British Library, Smithsonian Institute, Library of Congress of the United States, New York Public Library, to name a few.

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[4] Ken Henderson, "A rebirth in digital recording," *IEE Review*, 1999: 13-16.
[5] Nilay Patel, "Status Symbols: MiniDisc," *The Verge*, Feb 15, 2013, https://www.theverge.com/2013/2/15/3989872/status-symbols-sony-minidisc.
[6] Jeff Parsons, "MiniDisc: The format that failed: Last Sony MiniDisc players will ship in March," *T3*, Feb 1, 2013, https://www.t3.com/news/minidisc-the-format-that-failed.
[7] E. Paul Ratazzi, "MiniDisc: Successful Innovation or Just Cool Technology?," (Report submitted to course DSES 6470, Rensselaer Polytechnic Institute, Troy, NY, 2004), 12-14.

Given the relatively wide usage of MiniDisc in memory institutions and media organizations, the news about Sony discontinued manufacturing MiniDisc players and thus MiniDisc becomes an obsolete media raises an alarm to archivists, especially audiovisual (AV) archivists. In addition, due to the relatively short life of MiniDisc compared to its counterparts in the media format forest, systematic research on its technical mechanism and technical development, documentation of handling this media format, including how to effectively retrieve and archive audio information stored in the optical-disc medium, and recommendation on how to preserve MiniDisc-recorded audio information for long-term usage are limited.[8] Such nebulous situation further places AV archivists in a conundrum when facing archival collections that contain MiniDisc materials.

"The role of optical media in archives has shifted in the past decade from preservation medium to at-risk format", noted by Alexander Duryee in his article on optical media preservation[9]. International Association of Sound and Audiovisual Archives (IASA) in its *Guidelines on the Production and Preservation of Digital Audio Objects* clearly states that "the use of Minidisc as an original recording machine is not recommended"[10], mainly because of the proprietary data compression format adopted in MiniDisc, which may lead to misinterpretation of data during the archival process.[11] Annie Schweikert, in "An Optical Media Preservation Strategy for New York University's Fales Library & Special Collections" succinctly pointed out

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[8] Most academic or professional research on MiniDisc are material manufacturing and sound engineering based, such as the technical reports published by Sony, research articles published by the Institute of Electrical and Electronics Engineers (IEEE), and sound-engineering handbooks.

[9] Alexander Duryee, "An Introduction to Optical Media Preservation," *Code4Lib Journal*, 24, April 16, 2014, https://journal.code4lib.org/articles/9581

[10] "5.6.10 MiniDisc," Guidelines on the Production and Preservation of Digital Audio Objects (web edition), Second edition, 2009, IASA Technical Committee, https://www.iasa-web.org/tc04/minidisc

[11] "5.7.2 Field Recording Standards," Guidelines on the Production and Preservation of Digital Audio Objects (web edition), Second edition, 2009, IASA Technical Committee, https://www.iasa-web.org/tc04/field-recording-standards

that “optical disc and their drives are becoming rarer as trends in hardware, production, and storage shift to file-based media. The discs themselves may not last long enough to become obsolete; both the discs and their signals are susceptible to data loss, and their failure is difficult to predict”.[12] It is time to mind your discs.

This thesis attempts to address the above-mentioned puzzles related to MiniDisc. In this thesis, MiniDisc, as the central theme, is discussed as a media format instead of a physical medium or a recorder-player.[13] In the main body of the thesis, the first part (Chapter Two) provides an overview of the history and technical investigation of MiniDisc. Knowledge about the technical characteristics of MiniDisc is important for AV archivists to understand the data arrangement and structure stored in MiniDisc. In Chapter Three, the thesis discusses the current status of MiniDisc collections in archives and the existing workflows adopted by AV professionals in order to archive MiniDisc audio information. Contents in this section are based on interviews with AV professionals currently working in some prominent archival organizations and second-hand information obtained from online resources. Chapter Four documents different approaches of retrieving and archiving audio information stored in MiniDisc based on first-hand lab experiments. Chapter Five, the concluding section reviews MiniDisc preservation issues and proposes future research directions. This thesis serves two purposes: to provide technical investigations into the MiniDisc format and to explore practical and effective workflows of archiving MiniDisc contents for long-term preservation. The latter one will serve as a record of reference for the archival community.

12 Annie Schweikert, “An Optical Media Preservation Strategy for New York University’s Fales Library & Special Collections,” Graduate internship report, NYU Moving Image Archiving and Preservation, 2018, https://archive.nyu.edu/bitstream/2451/43877/2/Schweikert_OpticalMediaPreservationNYU_2018.pdf , 4
13 In daily life, when talking about MiniDisc or its short-form MD, people may refer to the physical MiniDisc cartridge or the recorder-player device.

Chapter Two: History, Technology and Development of MiniDisc

Sony - "A Corporate Guinea Pig"

Before delving into the history and technology of MiniDisc, a brief overview of Sony – the Japan-based world-leading pioneer of audiovisual electronics - is necessary. In 1945, when Japan rebuilt the country from ashes of World War II, Tokyo Telecommunications Research Institute, the predecessor of nowadays Sony Corporation (hereafter Sony) was established by Masaru Ibuka in Tokyo. Ibuka was an electronic engineer who graduated from Waseda University. Back then, the institute mainly repaired and remodeled different types of radios, an electronic product in high demand in the post-war era when Japanese were eager to learn from the world in rebuilding the economy. Ibuka's radio business was later joined by his old-time research fellow Akio Morita. In 1946, they co-founded Tokyo Telecommunications Engineering Corporation (aka Tokyo Tsushin Kogyo). Made up of a large group of young and energetic engineers, the corporation endeavored to catch the pace of the world's latest technological advancement. They successfully produced Japan's first magnetic audio recording tapes and recorders in 1950 and launched the country's first transistor radio in 1955. Their TR-52 super-receive R prototype transistor radio was released in January 1955, only one month after the launch of the world's first transistor radio (model TR-1) which was made in the United States.

Tokyo Tsushin Kogyo changed their name to Sony in 1958.[14] Over the decades, Sony has played a pioneering role in Japan by non-stop introducing innovative audiovisual products for both industrial and consumer markets, for example, the video tape recorder (VTR), transistor

[14] The adaptation of the name Sony was intended to help marketing Japanese-made electronic devices in the North American market, where people could easily pronounce this two-syllable brand-name. Sony crossed the Latin word "sonus", from which "sound" and "sonic" are originated. See "Chapter 6", Sony History Part I, Sony, https://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/1-06.html

television, and the world's first home-use video camera recorder (VCR). Sony gradually becomes a world-known brand as their high-quality and affordable electronic devices are widely sold and well received in overseas markets, especially in North America. Because of the company's never-ceasing exploration of new media formats and equipment, Sony is called "a corporate guinea pig". [15]

Sony has been known for heavily investing in their research and development (R&D) department, which was ran by engineers armed with "determination and scientist-like scrupulousness".[16] In the school of magnetic-based tapes, Sony kept advancing their footstep by introducing tapes and recorders in smaller and smaller size: from the country's first magnetic-based audio recording system, to U-matic, Betamax, 8mm Video8, "passport-size" camcorder, to the invention of the audio cassette Walkman system – "Listening to stereophonic sound while walking" hit the market in 1979 which soon became a global chic.

In the digital realm, since the early 1970s, Sony commenced their endeavor in the digitization of sound. In 1980, Sony and Holland-origin Philips presented to the world the 12-cm-diameter optical disc which records digital audio information in 44.1kHz sampling frequency and 16 bits - compact disc (CD). The invention of CD was expected to replace the analog-based vinyl long-play disc (LP). When the CD recording and playing-back system was introduced to the mass market in 1982, the Sony-Philips optical disc system became quickly accepted as the industrial standard. Soon after, Sony's first portable CD player "D-50" swept the market, nicknamed "Discman" and shared the equally huge popularity with Sony's audio cassette Walkman. In the following years, CD turned to be the dominant format in the popular music

[15] "Sony History Part I," Sony, https://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/
[16] "Sony History Part I, Chapter 9," Sony, https://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/1-09.html

industry, with skyrocketing commercial titles released in CD albums. Sony, once again, was the industry leader as its CD market share once reached to 70%.[17]

A decade after the launch of CD, Sony envisioned another presumably world-championing move. Norio Ohga, a musician and Sony's president at that time, introduced to the world a media format that was never seen before – MiniDisc.

The Birth of MiniDisc

Research and development of MiniDisc technology began in 1986. Even though the world witnessed the rising sales and demands of CD which produces finer sonic quality and provides track location functions thanks to the born-digital recording-playing technology, audio cassette tapes and personal audio cassette Walkmans were still greatly popular due to their low cost, editability and personalization. Taking these factors into consideration, Sony's audio R&D team – the Audio Development Group decided to invent a new media format that could inherit the digital advantage of CD while maintaining the rewritable flexibility of audio cassette tape. A special MiniDisc unit was soon formed.

Jan Maes, a member at the Sony Service Centre (Europe), in the Sony MiniDisc guidebook, listed the targeted features of MiniDisc when the media format was being designed: Digital disc format; Smaller than compact disc, but with the same timewise amount of music; High quality, up to compact disc level; Recordable; Enabling quick and random access; High shock-proof capability; Lightweight and inexpensive; and Durable.[18]

Although Sony and Philips had partnered successfully in the development of CD, this time they had unsolvable disagreements, and eventually they decided to invent their own new

[17] "Sony History Part II," Sony, https://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/
[18] Jan Maes, *The Minidisc* (Oxford: Focal Press, 1996), 2.

media format separately. In the mid-1980s, a magneto-optical (MO) recording-playing mechanism was under experiment in Sony, a technology based on which engineers hoped to develop a newer disc-based medium. Engineers Tadao Yoshida and Kazuhiko Fujiie, who were part of the team that developed the CD, were once again brought into this new project. At the same time, leaders of Sony's music entertainment sector started to acquire music titles to be produced in pre-recorded MiniDisc albums and persuade record companies to join the force. [19]

Sony finally concluded the invention of MiniDisc format in May 1991. MiniDisc media, recording-playing equipment and computer software were officially launched in December 1992 (Figure 1). Launching MiniDisc in 1992 was to commemorate the ten-year anniversary of Sony's remarkably successful CD technology. Upon the arrival of MiniDisc, Sony predicted that "all analog audio is being supplemented by digital audio".[20] Corresponding to this mission, MiniDisc was designed to be the first recordable, recordable, erasable, and random track accessible optical disc of digital audio format in the music consumption market.[21]

The full line of MiniDisc system was first available in Japan, followed by the European and North American markets. In November 1992, Japanese consumers were bombarded by the arrival of the Sony MiniDisc recordable-playback MZ-1 model, the playback only MZ-2P model, and the record-only MDW-60 model, along with 88 album titles released in MiniDisc format produced by Sony Music Entertainment (Japan).[22] Very soon in December 1992, MiniDisc products became available in the European and North American markets.

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[19] "MiniDisc : A Replacement for the Audio Compact Cassette," Sony History Part II, Sony, https://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/2-10.html#block4
[20] Jan Maes, 1.
[21] Ken C. Pohlman, *Principles of Digital Audio*, 5th ed. (New York, Chicago and San Francisco: McGraw-Hill, 1995), 418.
[22] "Hardware and Software Get an Early Start," Sony History Part II, Sony, https://www.sony.net/SonyInfo/CorporateInfo/History/SonyHistory/2-10.html#block5

Figure 1. MiniDisc Logotype created by Sony[23]

Sony underlined two features of MiniDisc. First, MiniDisc allows consumers to record new audio information and overwrite old information on high-quality but affordable optical discs, allowing cassette-tape alike flexibility to users. [24] Second, MiniDisc was regarded the successor to CD in terms of the optical disc material base and the sonic-quality projected, yet MiniDisc showcased greater advantages – smaller in size, more durable in everyday use and rewritable in nature. The palm-sized MiniDisc which holds the same capacity (74-minute-long recording time) as a CD was achieved through a Sony proprietary data compression method - Adaptive Transform Acoustic Coding (ATRAC) (more discussion about ATRAC will follow soon). The introduction of MiniDisc demonstrated Sony's ambition to replace analog cassette tapes and CDs with MiniDisc in the worldwide consumer market.[25]

Technical specifications and parameters of MiniDisc are documented in what is called the "Rainbow Book". The naming of this book was consistent with a series of optical disc media industrial technical standard guidebooks that were co-developed by Sony and Philips since the 1980s.[26] The Red Book (1980) was the CD book, the Yellow Book (1988) for CD-ROM (Read Only Memory) and the Orange Book (1990) for CD-MO/WO (Magneto-Optical disc and Write

[23] "MiniDisc Logotype," Sony Design, Sony, https://www.sony.net/Fun/design/history/product/1990/minidisk.html
[24] The first MiniDisc was actually a non-recordable one. But very soon, Sony flooded the consumer market with recordable MiniDiscs. See Maes, 23.
[25] Tadao Yoshida, "The Rewritable MiniDisc System," *IEEE* 82 (1994), 1492.
[26] These books, co-developed by Sony and Philips - two sound technology leaders, outline the basic parameters and specifications for each media, in order to standardize the formats for international manufacturers and markets.

Once disc). CD-MO is a type of optical disc that allows multiple-time data recording thanks to the MO mechanism. With the debut of MiniDisc – a revolutionary media format in Sony's ambitious blueprint, Sony produced the correspondent color-themed MiniDisc guidebook, but the book was given a more sensational name - the Rainbow Book. Such buzzing title naming indicated that MiniDisc was designed to embrace all technological advantages of its predecessors.[27] The relationship between MiniDisc and other preceding optical disc media formats is illustrated in Figure 2.

The first patent application for MiniDisc was filed by Sony in 1991, standardizing the recording region at a MiniDisc "is in the range from 28 mm to 50 mm."[28] Soon after, a more comprehensive patent of MiniDisc was filed in 1993, in which a detailed illustration of the MiniDisc block diagram, the ATRAC data compression algorithm, the magneto-optical information recording-readout mechanism and other MiniDisc features were documented.[29] In the following years, Sony continuously registered patents for their newer ATRAC versions. In addition, Sony also registered patents for different MiniDisc mastering methods, magnetic-optical heads, and versatile functions of different MiniDisc recorder-player models.[30]

That being said, the introduction of MiniDisc was not without competition. Instead, its strongest rival (and one-time partner) Philips was developing its own digital media format. In 1992, the born-digital magnetic tape based Digital Compact Cassette (DCC) was launched by

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27 Maes, 3-5.

28 Katsuaki Tsurushima and Tadao Yoshida, Disc-shaped recording medium, US patent 5,244,705, filed Aug 19, 1991, and issued Sept 14, 1993. Full patent file could be retrieved from http://www.minidisc.org/patents/pdfs/US05244705.pdf

29 Tadao Yoshida, Disk recording/reproducing apparatus and disks applied therein, US patent 5,552,896, filed Nov. 18, 1993, and issued Sept. 3, 1996. Full patent file could be retrieved from http://www.minidisc.org/patents/pdfs/US05552896.pdf

30 A list of patents is integrated by MiniDisc researcher Eric Woudenberg, see http://www.minidisc.org/patents/

Philips[31]. While the DCC format showed some degrees of backward compatibility because they believed people were still fond of analog cassettes, Sony's MiniDisc was a thoroughly brand-new media format. Compared to Sony's MiniDisc-exclusive Walkmans, Philips' DCC players could playback analog cassette tapes, but only DCC cassettes were able to be both recorded and played-back on DCC players.

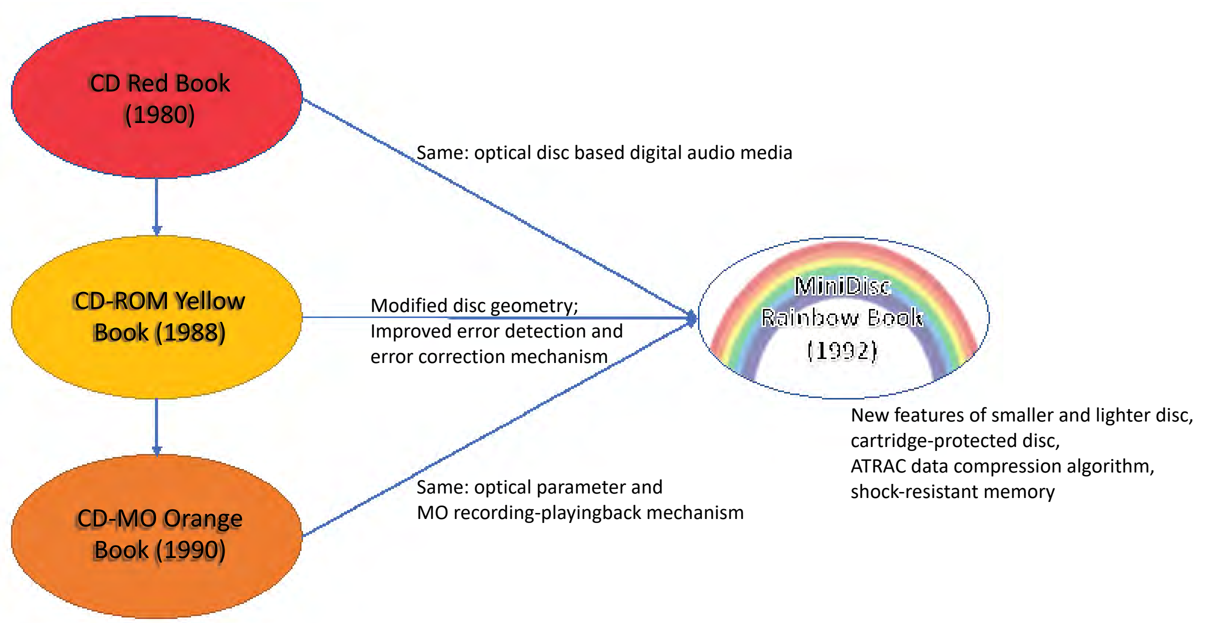

Figure 2. Relation between MiniDisc and preceding optical disc formats[32]

Technical Specifications of MiniDisc

Physical parameters

From the appearance, the appearance of a MiniDisc resembles a mini-size CD embedded in a plastic cartridge. The cartridge is mainly for protection of the disc. The disc is made out of polymer materials with a mirror-like reflective metallic surface. The whole cartridge is palm-size

[31] Interestingly, we can see advertisements of MiniDisc and DCC were placed side by side in the same issue of Billboard in 1993. See "This is it," *Billboard*, March 13, 1993, 92-93. "How Many 'Firsts' Can You Expect From Your Suppliers of DCC Cassettes?" *Billboard*, March 13, 1993, 95.
[32] Referred to and adapted from Maes, 4.

and light weighted. There is a metal shutter at one side of the cartridge. By default, the shutter is closed to protect the disc. Similar to many recordable media with cartridge protection (e.g. Video Home System - VHS tapes), there is a tiny switch – write protector - on the MiniDisc cartridge (Figures 3 & 4). Note that the below MiniDisc parameters mainly refer to the standard-play MiniDisc media which represent the first generation of this media format. Over the years, newer generations of MiniDisc were gradually introduced by Sony. More discussion on the newer generations will follow later.

Figure 3. Appearance of a standard MiniDisc media

Below are physical specifications of a standard MiniDisc media:

- Size of cartridge: 72 X 68 X 5mm
- Weight: 30g (including disc)
- Playing and recording time of disc: 60, 74 or 80 minutes
- Storage capacity: 219 - 291MB[33]
- Diameter of the disc: 64mm
- Thickness of the disc: 1.2mm

[33] 219MB for 60-minute disc, 270MB for 74-minute disc, 291MB for 80-minute disc. All of them reserve 1.65MB for disc management space, making the actual recording space less than the original storage capacity.

- Diameter of center hole: 11mm
- Clamping area[34]: 16.4mm
- Starting diameter of lead-in area: 29mm max
- Outer diameter of lead-in area: 32mm (similar to CD, recording on MiniDisc starts from the inner to the outer area)
- Track pitch: 1.6µm

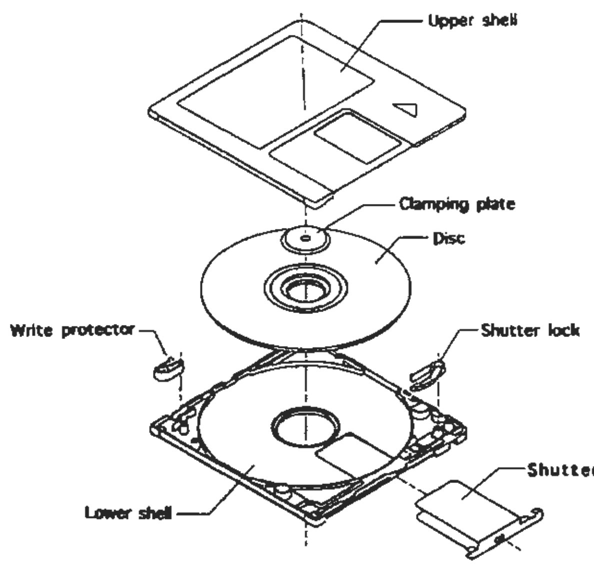

Figure 4. Cartridge exploded view[35]

Technical parameters

Generally speaking, in terms of audio recording, MiniDisc showcases similar features to CD, with audio information recorded at 44.1 kHz, 16 bits, but 24-bit recording is available in a later generation MiniDisc called Hi-MD. MiniDisc recorders use a perceptual-based data compression method called ATRAC. It reduces by 5:1 the storage needed for digital audio (more

[34] A center clamp that holds and stabilizes the disc at a precise position for laser readout and recording.
[35] Cited from Yoshida, 1495.

discussion on ATRAC in the following section). Below are some basic technical specifications of MiniDisc:

- Audio channels: Stereo or mono
- Wow and flutter[36]: Quartz crystal precision
- Sampling frequency: 16 bits, 44.1kHz per second (the same as CD's)
- Recording bit rate: 292kbps (1/5 of CD's)
- Modulation: EFM (eight to fourteen modulation) (the same as CD's)[37]
- Error correction system: Advanced CIRC (ACIRC) (improved from CD and CD-ROM)[38]
- Coding: ATRAC
- Information recording and readout: Magneto-optical

Track layout

The track layout of MiniDisc also showcases distinctive features of MiniDisc. Premaster/pre-recorded MiniDisc shares the similar track layout with CD, which consists of a lead-in area for storing the table of contents, a program area which holds music information, and a lead-out area. But for recordable MiniDisc, the track layout is more sophisticated.

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[36] Measurement of wow and flutter is carried out on audio tape machines, cassette recorders and players, and other analog recording and reproduction devices with rotary components (e.g. movie projectors, turntables (vinyl recording), etc.) This measurement quantifies the amount of "frequency wobble". Refer to "Wow and flutter measurement," Wikipedia, updated Dec. 28, 2020, https://en.wikipedia.org/wiki/Wow_and_flutter_measurement

[37] Eight-to-fourteen modulation (EFM) is a data encoding technique. During audio recording, each sample of 16 bits are handled as two parts of 8 bits. Each 8-bit block is translated into a corresponding 14-bit block. This encoding method is intended to increase the efficiency and correction rate of optical readingout. Such modulation is chosen as to use ensure as few "1 to 0" and "0 to 1" transition as possible. Refer to "Eight-to-fourteen modulation," Wikipedia, updated Feb. 2, 2021, https://en.wikipedia.org/wiki/Eight-to-fourteen_modulation; Also refer to Maes, 8.

[38] CIRC means cross-interleaved Reed–Solomon code (CIRC). After analog signals are A/D converted to digital signals, the data is CIRC-encoded. This method allows the media player to correct high amount of readout errors. The original audio data is supplemented with additional data which has been calculated from the input audio data. CIRC adds to every three data bytes one redundant parity byte. Original audio data and supplemented data will then interleaved, to countermeasure for errors, mainly burst errors. Refer to Maes, 8.

In a recordable MiniDisc, there are non-recordable and recordable areas. The non-recordable area is similar to the lead-in area, carrying information such as the start and end address of the user table of contents (UTOC), laser power level and disc type. The recordable area starts with the UTOC, which is a key part of a recordable disc because it can be changed when the user makes a new recording activity. It is an index that records the location (start and end address) of every piece of audio track. Other information recorded by the UTOC also includes disc information, copy-protect codes, recording date and time. Following the UTOC area is the data area where audio information is stored and then the lead-out area (Figure 5).[39]

On MiniDisc surface, there is a wobbling pregrooved area starting from the inner circle of the disc swirling to the outer circle. This pregrooved area records information which will guide movement of laser beams during information recording. Though advanced audio engineering knowledge about this process is beyond the discussion scope of this thesis, to AV archivists and media preservationists, knowledge about the track layout of MiniDisc is important when they try to understand the data arrangement structure and the metadata location during data migration and digital preservation actions.

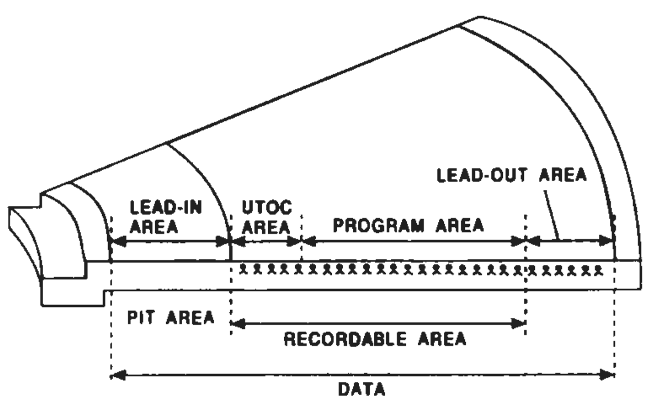

Figure 5. Track layout of recordable MiniDisc[40]

[39] Maes, 33-34.
[40] Maes, 34.

Recording and Playback Mechanisms of MiniDisc

MiniDisc stores data in a binary digital form (0 or 1) and it is through an analog (A)/digital (D) conversion mechanism in which analog audio information (e.g. human voice) is codified. There are usually two types of MiniDisc for the consumer market – premaster and recordable. The recordable MiniDisc was more widely used by consumers, such as in cultural and media institutions people used MiniDisc for recording interviews and different sorts of live sounds. In the category of recordable MiniDisc, besides the standard-play (SP) mode which Sony first launched to the market, MDLP (Long-play), NetMD and Hi-MD were gradually introduced by Sony over the years. These different versions of MiniDisc will be discussed later.

Premaster (Pre-recorded) MiniDisc

Before diving into recordable MiniDisc, understanding the general mechanisms of premaster/pre-recorded MiniDisc is useful. In terms of a premaster MiniDisc, the recording and playback mechanisms are the same as those of a premaster CD: analog data is A/D converted, encoded (control data is added) and modulated (for error correction). These processed data will be recorded on a spiral track, starting from inner to outer circle of the disc. The digitized data of either 1 or 0 will be reflected on the disc through pits (Figure 6), which are made from mother plates stamping on them.[41] The other side of the pits are bumps, which are later read out by laser beams projected from the side that touches the disc's polymer substrate. To read out the data, a laser light from the optical pickup will be projected onto the pits and subsequently different

[41] To make mother plates, metal masters were produced first. Metal masters store data in laser beam generated pits. The "shape" of the metal master, including how the pits are cut and aligned, is engraved to make mother plates. These mother plates then are used to stamp hundreds of thousands of consumer-use discs, producing the same "shape" of pits. The signal surface of each disc is then coated with a reflective material to enable optical readout. See Luc Baert et al., *Digital Audio and Compact Disc Technology*, 3rd ed. (Oxford, Focus Press, 1995), 113-115.

weights of reflective lights will be generated. The reflective lights then will be demodulated, decoded and D/A converted back to analog audible sounds.

Figure 6. Pits on a premaster disc[42]

As mentioned, MiniDisc was touted as a media format that embraces all advantages of its preceding optical disc-based media formats standardized in other monochromatic books. While the appearance and encoding-decoding methods of MiniDisc are similar to those of CD's, the recording-playback system of MiniDisc is actually more closely resemblance that of CD-MO/WO – a magneto-optical system that allows repeated data writing on the disc.[43] But what makes MiniDisc significantly different from and exceeding the technology of CD-MO/WO is a secret weapon – the ATRAC data compression algorithm.

Magneto-optical data recording of recordable MiniDisc

MiniDisc is embedded with more data processing systems than CD to optimize data recording and playback. MiniDisc requires both optical and magnetic heads to perform recording.

First, in the MiniDisc system, a magnetic-field modulation is introduced as a safer method to store data and a more advanced feature which allows re-writability. Different from the

[42] From Yoshida, 1494.
[43] Maes, 9-10.

optical-field modulation, which is involved in making premaster discs, the magnetic-field modulation here does not use pit but magnetic information to store data under the assistance of the optical force. The detailed mechanism is as followed.

This mechanism is based on a physical law which relates to what is called the "Curie temperature". Many metallic materials can be magnetically influenced by magnetic fields once their temperature hits a certain point – the Curie temperature (Curie point). Upon reaching that temperature, the metal itself will become a magnetic metal. Different metals have different Curie points. The process to write information on a MiniDisc is derived from this physical law.

The MiniDisc recording process could be demonstrated as followed: When data is being recorded, a laser beam will be used from one side to heat the metal layer on the disc up to its Curie point. At this temperature, the metal is magnetized. Meanwhile, the magnetic head at the other side writes data on the disc. Here, North or South pole equals to 1 or 0 in the digital realm (Figure 7). When conducting re-recording, old information will be immediately overwritten by the new information.[44]

This mechanism is similar to that of magnetic tapes where the metallic particles on the tape will change their directions as data is being written, but the creation of the magnetic data on MiniDisc is under an extremely high temperature environment. Such high temperature is beyond the scope of daily human activity. Therefore, the data stored under this magneto-optical system is more secure than those written on traditional magnetic tapes (e.g. cassette tapes). Generally speaking, such recording process theoretically allows for an endless number of overwriting and re-recording, as long as the metal layer is able to be heated up to the required point.

[44] Maes, 37-39; Yoshida, 1495.

Sony uses a material called ferri-cobalt-terbium (FeTbCo) as their magneto-optical layer on MiniDiscs (Figure 8). It is a type of metal with a relatively low Curie point (185 °C) compared to other metals and low coercivity that could most efficiently make such magneto-optical recording process happen.[45]

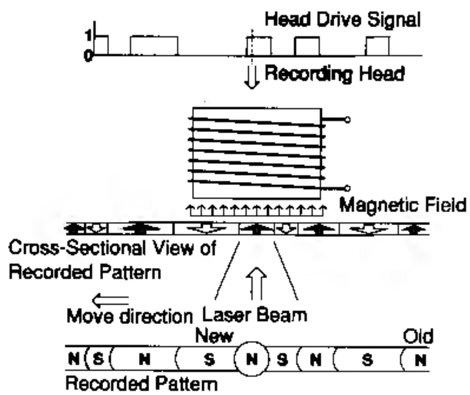

Figure 7. MiniDisc magnetic-field modulation recording and overwriting system[46]

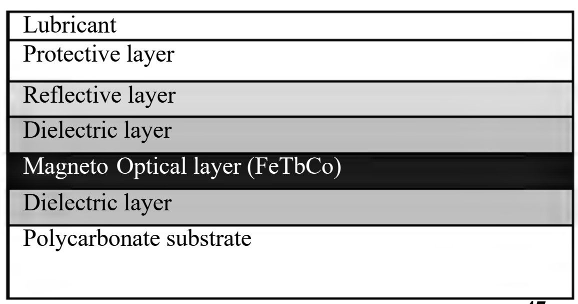

Figure 8. MiniDisc cross-section view[47]

Information readout from recordable MiniDisc

The readout of premaster MiniDisc is the same as that of CD. But the readout of recordable MiniDisc shows a different mechanism, which, as the previous section indicated, involves the roles played by both the magnetic field and the optical force.

[45] This means a relatively low magnetic field could write data on the disc.
[46] Yoshida, 1496.
[47] Modified by the author based on the pattern illustrated in Luc Baert et al., 239.

Readout of data from MiniDisc requires laser beams projected from the laser head. Laser light would hit the disc surface, pass through the magneto-optical layer and hit the reflective layer. After a laser beam hits the layer with information represented as South or North poles, the beam will be reflected by the reflective layer and then go through a Wollaston prism made of two bonded rock crystals. A feature of this special type of prism is that it will give out different outputs if receiving light beams reflected from different magnetic poles. Such a feature plays a significant role in MiniDisc's data readout. On a MiniDisc, data is written as a North or South pole to represent the digital binary 1 or 0. After the light beam goes through the magneto-optical layer and is reflected back to the Wollaston prism, the prism will send out a main beam and multiple side beams. A light beam reflected from different magnetic poles will have different shapes and angles of side beams accordingly, so that the readout of data is made possible[48].

ATRAC Data Compression Algorithm

In the early 1990s, Sony launched MiniDisc as a time-defining technology that could excel CD in many aspects. MiniDisc was therefore embedded with a number of features that were at more advanced level than those of CD, namely the aforementioned advanced cross interleaved reed/Solomon correction (ACIRC) encoder-decoder system, the address in pre-groove (ADIP) system, the shock resistance memory that gave stable acoustic experience to users, and the signature ATRAC perceptual-based data compression algorithm. ATRAC, short for "adaptive transform acoustic coding", is the secret weapon that allows MiniDisc to store the same size of data capacity on its 64mm-diameter disc which is much smaller than CD which has 120mm-diameter.

[48] The angle of the side beams is called Kerr angle. Luc Baert et al.,240-242.

With the ATRAC data compression, audio information recorded in MiniDisc media is stored in an ATRAC codec wrapped by the .oma format.[49] The .oma files sometimes contain DRM (Digital Rights Management) copy protection which prevent music from being played on unauthorized devices. Note that Sony's support for .oma format was discontinued in 2008.[50]

The theory behind the operation of ATRAC is the human perception of sound, called "psycho acoustics". This psycho acoustic theory, which buttresses the utility of ATRAC is based on several assumptions. First, as the sensitivity of our hearing system is not linear over the theoretically audible range of 20Hz and 20kHz, sounds at certain frequencies are actually less perceivable or even unperceivable compared to others. Sound at a minimum level of perceivable is regarded as the threshold of hearing. That is to say, sounds below this threshold become less useful and thus could be omitted to save room. Another key mechanism behind the psycho acoustic theory is called masking. When audible sounds at a lower frequency are covered/masked by a higher frequency sound, the former one actually becomes inaudible. By analysing each frequency of sound at a given moment, the system could delete those frequencies that are masked. The third mechanism is related to critical bands. In critical bands, signals appear not to be separated according to human ears. That is to say, the sensitivity of human hearing in the frequency domain of a critical band is equal. 24 critical bands have been identified by scientists. If a system can analyse the composing frequencies of a sound and distinguish the frequencies that are within critical bands, data could be reduced to save room while to human ears, the sound quality remains the same.[51]

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[49] Due to the high proprietary nature of the ATRAC codec, audiovisual preservation tools such as MediaInfo and ExifTool are not able to identify this codec. But the .oma wrapper is usually identifiable.
[50] "What is an oma file?," File.org, https://file.org/extension/oma
[51] Maes, 61-63.

Generally speaking, it is based on these psycho-acoustic mechanisms that ATRAC is developed. By mathematically and sophisticatedly analysing the input audio, the MiniDisc recording system can define, split, and transform the data into a smaller size for storage while maintaining the perceived high sonic quality, because the audio information eliminated is defined as "uncritical" to the general sound quality.[52] During recording, audio information goes through the ATRAC encoding system before reaching to the EFM and ACIRC modulations. During data readout, the ATRAC encoded data will first go through EFM and ACIRC before reaching to ATRAC for decoding (Figure 9).

After the sound information going through the ATRAC system – a mathematical "decision making" process, the bit rate of MiniDisc could reach as low as 292kbps (approximately 0.3Mbps), 1/5 the bit rate of CD's 1.4Mbps.[53] A vivid example is the sound of "silence". If recorded to a CD, it would still require 1.4Mbps bit rate because the CD recording system does not tell the difference between the sound of "silence" and the actual audible sound – they are both data to be stored. But in MiniDisc, the sound of "silence" is defined as "insignificant" or "inaudible" according to the embedded ATRAC system, and therefore this "silent" part of sound is eliminated to save space for more critical and audible sounds.

Obviously, audio information stored in MiniDisc is in a compressed mode. Hence, MiniDisc is seldom seen as an ideal archival medium. Over the years, newer generations of MiniDisc media and ATRAC codecs were developed (more discussion in the next section).

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[52] Maes, 65.
[53] Bit stream 16 bit, 2 channels, 44.1 kHz sampling rate comes out with the CD bit rate calculation formula as 16 X 44.1 X 2 = 1.4Mbps.

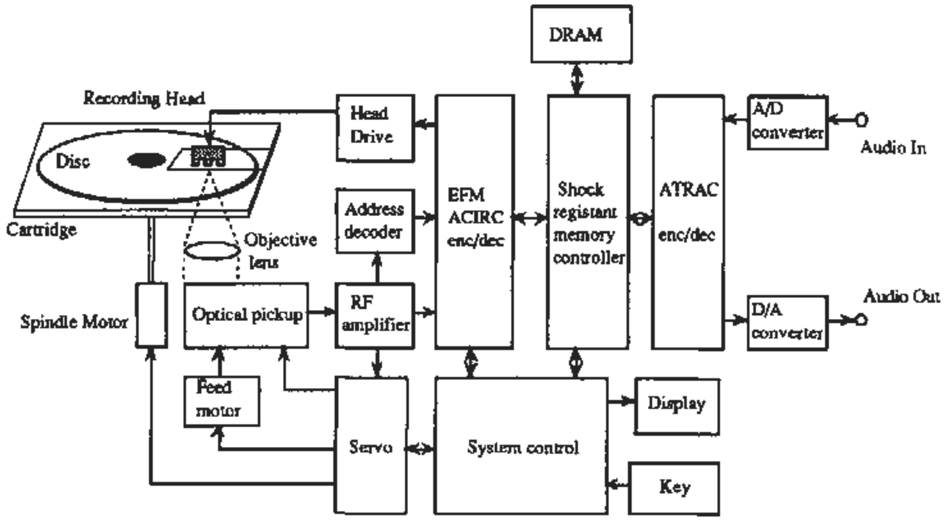

Figure 9. Full block diagram of MiniDisc[54]

Development of MiniDisc Technology

What has been discussed so far is mostly the fundamental yet early version of how audio information is written on and readout from MiniDisc media. Over the years, the technology of the MiniDisc system evolved. Sony, to actively engage MiniDisc in the fierce race in the music industry and in the Internet era, kept introducing new modes of MiniDisc recording and playing. It is important to note that, all these new modes of recording could be made on the standard-type of disc – the MiniDisc media introduced in 1992. It was not until 2004 that Sony launched its upgraded yet last version of MiniDisc media with significantly enlarged storage capacity and new technical parameters – the Hi-MD. Hi-MD refers to both the new type of MiniDisc media, MiniDisc recording mode and recording-playback device.

In September 2000, Sony developed MiniDisc long-play (MDLP), a new MiniDisc recording system that was especially designed for home-use decks, professional decks, and

[54] Maeda Yasuaki, "Minidisc System," *IEEE 1993 International Conference on Consumer Electronics Digest of Technical Papers* (1993), 124-125.

Sony's latest Memory Stick Walkman. There are two MDLP modes: one makes MiniDisc media accommodate 160-minutes audio in stereo mode ("LP2"), and the second one records audio in 320-minutes' long in stereo mode ("LP4"). MDLP players employ the ATRAC3 data compression method, a more advanced generation of ATRAC algorithm.[55] In order to create the long-play mode (accommodate more audio information in the disc), ATRAC3 further compresses the data while ensuring the sonic quality. The bit rate of LP2 is 132kbps and LP4 is 66kbps.[56] For playing back a MiniDisc media recorded in the MDLP mode, users have to use players or decks that are compatible with the MDLP mode. Playing MDLP media in a non-MDLP player would result in silent tracks. But MDLP-compatible players could play back SP-mode MiniDiscs.

In mid-2001, NetMD – a new type of MiniDisc device was introduced, a move that Sony made to catch up with the rapid Internet advancing pace and the soaring prevalence of personal computers. By using NetMD players, audio information could be directly transferred from personal computers to MiniDisc media via the USB interface. Such a data transfer method is much faster than old-time real-time recording. Though NetMD devices can write data on MiniDisc media through direct computer transfer, they still can record audio information in the traditional manner. NetMD can record and playback MiniDisc at SP and LP modes.[57] NetMD also adapted both ATRAC and ATRAC3 compression modes. If music tracks in .mp3 format were transferred from a computer to a MiniDisc media, the NetMD would automatically apply

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[55] Before ATRAC3, actually there were already different generations of ATRAC developed by Sony, namely different versions of ATRAC1 and ATRAC1 Type R. See "Minidisc FAQ: MDLP ('Long-Play') Mode Topics," minidisc.org, https://minidisc.org/mdlpfaq.html and "Minidisc FAQ: Audio Topics," minidisc.org, https://minidisc.org/faq_sec_4.html#_q27
[56] For the technical details of ATRAC3, see "ATRAC3 High-Quality Audio Encoding Technology," Techno World, n.d., available in minidisc.org via https://minidisc.org/atrac3_article.pdf
[57] Refer to "MZ-N505 Portable MiniDisc Recorder User Manual," available via https://minidisc.org/manuals/sony/sony_mzn505_manual.pdf

the ATRAC3 data compression on the music tracks before they could be played. Since the introduction of NetMD, designated computer software is needed for users to transfer data from their personal computers to MiniDisc media. First, Sony introduced “Open MG Jukebox” as the software for their first generation NetMD. It was until model MZ-N10 that “SonicStage” replaced the Jukebox. In the United States market, Sony provided the “Simple Burner” software. Installation packages of these software came along with the MiniDisc players when consumers made a purchase. All of them are proprietary.

Also worth noting: In NetMD system, though some of them were enabled to be directly connected with personal computers, the transfer of audio contents was one-way only: from computer to MiniDisc player. It is not until the invention of the Hi-MD system that audio data could be flexibly transmitted back-and-forth between personal computers and MiniDisc players.

In January 2004, Sony introduced Hi-MD, which, unfortunately, is the last generation of MiniDisc system. A noticeable change of Hi-MD was that Hi-MD could not only save audio information, but also non-audio data such as documents and images. Hi-MD media stores information in a FAT (File Allocation Table) system.

In terms of audio recording, the Hi-MD system not only introduced a new mode of magneto-optical recording method, but also brought forth two new types of MiniDisc media - a new model media with 1GB storage space and a 305MB media which physically resembles the old type of MiniDisc media while doubling the storage capacity (Figure 10). Hi-MD recorders could record audio information on Hi-MD media in the uncompressed linear PCM format (pulse code modulation) at 16 bits and 44.1kHz. Hi-MD media could also be recorded in a compressed mode with Sony's ATRAC3plus encoding method which leads to recording bit rate at 256kbps (for “Hi-SP”) and 64kbps (for “Hi-LP”). Same as its predecessor NetMD, Hi-MD players could be connected to personal computers via USB interface. While NetMD only allows users to download music into their players, Hi-MD enables two-direction transfer, which means that audio information recorded on Hi-MD media could be uploaded to personal computers via the SonicStage software.[58]

Figure 10. Appearance of a Hi-MD media

It is noteworthy that, the 1GB-capacity Hi-MD media is a revamped model compared to the traditional MiniDisc. The disc consists of three layers instead of one layer for data writing-in. Though recording information on this new type of Hi-MD media still relies on the magneto-optical mechanism, Hi-MD devices adopt a new approach to readout audio information. This new approach is called Domain Wall Displacement Detection (DWDD). Research about the DWDD approach is beyond the scope of this thesis, but generally speaking, with DWDD, audio sound could be recorded in a finer quality because the spots that represent the data are made smaller than traditional laser spots.[59] In terms of the 305MB-capacity type of MiniDisc, even though its physical parameters and technical specifications are the same as the traditional type of MiniDisc, when being recorded, the modulation system was changed from the traditional EFM

[58] "MiniDisc FAQ: Hi-MD Topics," minidisc.org, https://minidisc.org/hi-md_faq.html
[59] Ran Ren, "Domain Wall Displacement Detection Technology Research Report," OpenStax CNX, https://cnx.org/contents/NmnfGPIX@1/Domain-Wall-Displacement-Detection-Technology-Research-Report

mode to the more efficient RLL mode (Run-length limited).[60] Again, research on these sound engineering technologies is far from the intention of this thesis.

Hi-MD devices could playback MiniDisc media recorded in SPMD, MDLP and Hi-MD modes – the most versatile backward compatibility among all MiniDisc players. In terms of recording, Hi-MD devices could also generally record audio information in Hi-MD modes (PCM, Hi-SP, Hi-LP) and other preceding modes (SP, LP2, LP4). But recordings made in the pre-Hi-MD modes could only be made possible on non-Hi-MD media. Figure 11 shows the different recording modes and resulting media which could be accomplished by the standard MiniDisc media and Hi-MD media.

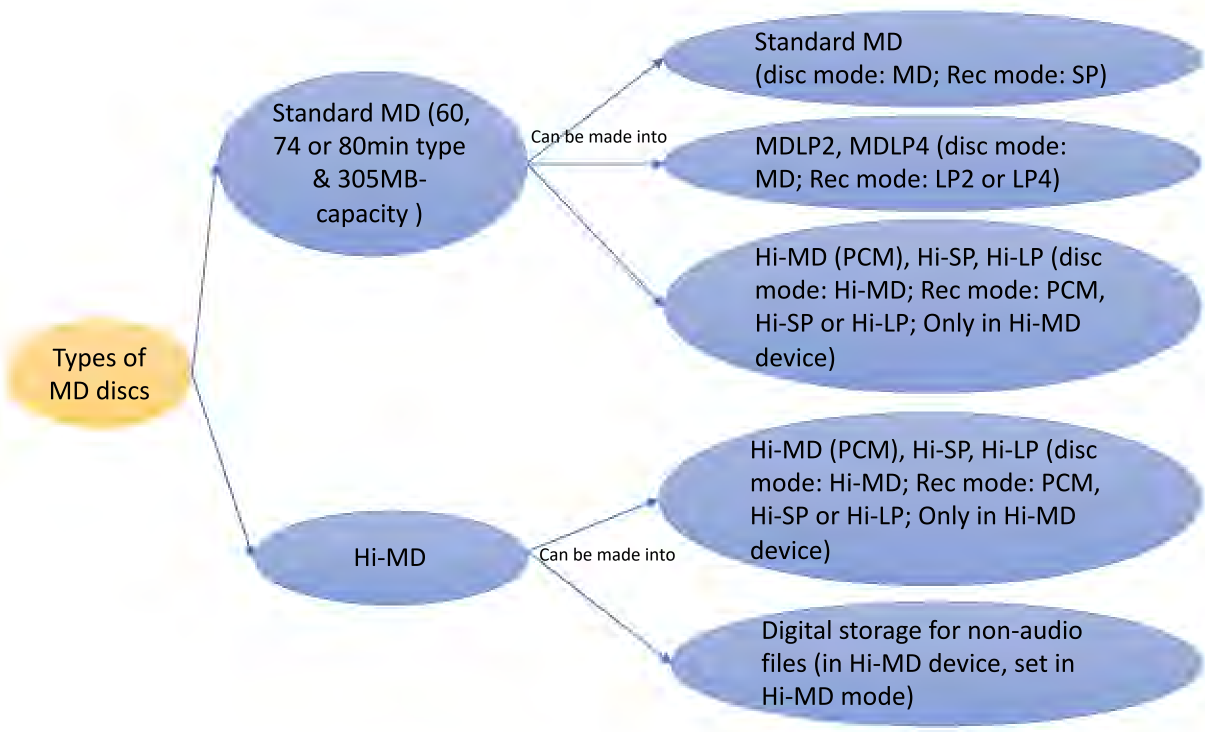

Figure 11. Different recording modes accomplished by Standard MD and Hi-MD media

[60] "MiniDisc FAQ: Hi-MD Topics"

From the onset of the MiniDisc technology in 1992 to the last generation of MiniDisc system in 2004, Sony never ceased upgrading this media format and its entire recording system. From AV archivists' point of view, if MiniDisc collections are included in an archival repository, it is important to note that not only the media type, but also the recording mode. Though generally speaking, in terms of playing-back, MiniDisc players are backward compatible (e.g. Hi-MD device could playback audio recorded in standard mode), it is wise for archivists to understand the basic technical parameters when the audio information was originally recorded. With different recording modes, the technical metadata of the recorded audio information could vary significantly. While archivists might be unable to tell the original recording mode by examining a physical media, the table below (Table 1) provides some useful hints.

It is recommended that archival organizations which hold MiniDisc collections purchase Hi-MD players in order to playback MiniDisc media recorded in different modes.

MiniDisc Recorder Encoding Mode	**Recording Capacity**		
(All the encoding modes record audio at 16 bits, 44.1 kHz)	**1GB Hi-MD**	**305MB Hi-MD**	**Standard MiniDisc (SDMD)**
Linear PCM (1.4Mbps, uncompressed)	1h 34m	28m	Not compatible
Hi-SP (256kbps, ATRAC3plus)	7h 55m	2h 20m	Not compatible
Hi-LP (64kbps, ATRAC3plus)	34h	10h 10m	Not compatible
MDLP2 (132kbps, ATRAC3)	16h 30m	4h 50m	2h 40m
MDLP4 (66kbps, ATRAC3)	32h 50m	9h 50m	5h 20m
Standard (292kbps, ATRAC)	Not compatible	Not compatible	60m or 74m or 80m
Note: Recordings made by Hi-MD recorders in non-Hi-MD modes are possible made on discs formatted in the standard mode. MDLP is an encoding mode making recording on SDMD. There is no new type of disc coming along with MDLP. NetMD is a recording system which allows audio music directly transferred from personal computer to MiniDisc recorder. There is no new type of disc coming along with NetMD either.			

Table 1. Recording capacity of different MiniDisc media under different recording modes[61]

[61] Adapted from and modified based on "Minidisc FAQ: Hi-MD Topics", minidisc.org, https://minidisc.org/hi-md_faq.html

Development of MiniDisc Devices

There are different types of recording and playback devices for professional and consumer markets: portable player, portable recorder-player, decks, bookshelf, boombox, CD/MD deck, automobile deck, professional deck, professional multitrack, and data device (MiniDisc used for camera data storage).

To many MiniDisc users, the most familiar type is the portable one – MiniDisc Walkman. Sony, as the inventor of MiniDisc, dominated the device market. The first Sony MiniDisc recorder-player model was MZ1, released in 1992. It was a portable size with an LCD display on the surface. This first gadget was already equipped with almost all the features of MiniDisc technology: ATRAC encoding, shock-resistance memory, track searching and shuffling, and most importantly, the magneto-optical recording and readout system. In 1993, a second generation of ATRAC was launched in Sony's second portable MiniDisc recorder-player model MZ-R2, and the third generation in 1995. Starting from the MZ-R2 model, a stick controller was installed, bridging the earphone and the device. In every new type, Sony kept adding new functional buttons to their MiniDisc devices, making processes of recording, song selection, and song title input more versatile. This is also why Sony filed a lot of patent registrations.

Since the beginning of the MiniDisc technology, Sony already licensed manufacturing of MiniDisc to other electronic companies. In a press release in Austria in 1992, then president of Sony announced 23 hardware companies, 8 software-related firms and 10 blank-media manufacturers have signed licensing agreements.[62] Besides Sony, prominent electronic manufacturers that produced MiniDisc devices included Sharp, Panasonic, Aiwa, JVC, and just

[62] "Sony Details MD Launch at Euro Press Gathering," *Billboard*, July 4, 1992, 47.

to name a few. But with little doubt, MiniDisc devices manufactured by Sony dominated the market. [63]

As mentioned, in 2001, to catch up with the pace of personal computer development, Sony introduced NetMD. The first NetMD by Sony was model MZ-N1. A USB connection was added to allow direct connection between personal computer and MiniDisc recorder-player, and an exclusive software was developed for users to manipulate the audio file transfer process. In 2004, Hi-MD was launched, symbolizing a new yet last era of Sony's MiniDisc technology. Since then, MiniDisc media could not only record audio information, but also digital contents of various types. Some later Hi-MD recorder models could even record audio in .mp3 format and are equipped with a camera lens, which means MiniDisc served a more data storage media function than an audio disc. The last model of Sony Hi-MD portable recorder-player is MZ-RH1. However, compared to its predecessors, the number of Hi-MD models is much fewer.[64]

MiniDisc Format Recession and Obsolescence

Against the background of rapid progression of digital media format and portable music players, MiniDisc started disappearing from the market since 2013 and became an obsolete media. One of the reasons is from the organization itself – Sony. In the late 1980s and early 1990s, then president of the company Norio Ohga envisioned the arrival of an era of recordable media and was confident that consumers already showed a preference for CD over magnetic cassette tapes. He decided to produce the CD-like MiniDisc. However, in fact, in that period of time consumers were still fond of using cassette tape as their primary recording media and CD

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[63] "Equipment Browser," minidisc.org, http://www.minidisc.org/equipment_browser.html
[64] Ibid.

consumption was a relatively expensive one.[65] Such mis-judgement set an unsolid foundation for Sony's supposedly revolutionary MiniDisc invention. Second, price always plays a role in the demise of MiniDisc technology. The first Sony MiniDisc recorder-player costed $750 – an astonishingly high price to general consumers, and black MiniDisc media costed $23.4.[66] [67] Music listeners, especially teenagers, still preferred using the more affordable cassette tapes. In 1998, 6 years after the launch of MiniDisc, in the Japanese market, 230 million cassette tapes were sold while the sales number of MiniDisc was only 91 million units.[68] The third reason is the limited number of premaster MiniDisc available in the market. In 1992, when Sony heralded this technological innovation to the global market, there were already some global major record labels that had little interest in making premaster MiniDisc titles. For many years, Sony was the only major record label that released premaster MiniDisc titles. Until 1999, they had only produced several hundred album titles.[69] [70]

Last but not least, an important reason for MiniDisc's failing destiny was an external factor: the swift growth of personal computer users in the millennium years. Subsequently, computer-derived media formats, such as .mp3, .wav, and .FLAC, mushroomed. With a palm-size MP3 player, music lovers can simply transfer music from their computers to the devices without installing any software. What's more, the iPod from Apple which soon became a fad. The first-generation iPod offered a capacity of 5GB which could store around 1000 songs – a capacity that significantly outshined MiniDisc.

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[65] Ratazzi, 5-6.
[66] Faulkner.
[67] "Sony Details MD Launch at Euro Press Gathering," *Billboard*.
[68] Steve McClure, "Japan: MiniDisc Tops Home Recording," *Billboard*, July 24, 1999, 84.
[69] "Sony Details MD Launch at Euro Press Gathering," *Billboard*.
[70] Dominic Pride, "MiniDisc Revival Brewing Abroad," *Billboard*, July 24, 1999, 84.

Sony announced the ending of manufacturing of MiniDisc players in 2013, bringing this media format into "official" obsolete status. New blank MiniDisc media and MiniDisc recorder-players are mostly available in the second-hand market, while only a small number of manufacturers are still producing MiniDisc players.[71] According to Museum of Obsolete Media, MiniDisc is considered "vulnerable, or some risk" (level 2), meaning that "the format is no longer current but may still be in use, and equipment capable of reading the media is still relatively common even if no longer produced."[72]

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[71] TAEC and TASCAM are two Japanese manufacturers which are still running the line MiniDisc player manufacturing, while in small scale.

[72] "Obsolescence Ratings," Museum of Obsolete Media, https://obsoletemedia.org/media-preservation/obsolescence-ratings/.

Chapter Three: Retrieving and Archiving MiniDisc Contents – Existing Workflows

MiniDisc, Sony's "guinea pig" and ambitious invention, with little doubt, has now become an obsolete media format after its less-than-two-decade heyday. As mentioned, during the late 1990s and the early 2000s, not only were general music consumers fond of MiniDisc, but also different types of cultural institutions and media organizations utilized MiniDisc as one of their major forms of audio information storage. With the recession and obsolescence of MiniDisc, it is time for archivists and media custodians to have their heads up: how to take good care of the digital information captured by and stored in MiniDisc media for long-term usage?

According to the definition given by the Digital Preservation Coalition, digital preservation is "the series of managed activities necessary to ensure continued access to digital materials for as long as necessary."[73] However, getting access to the digital information stored in MiniDisc media already presents a big challenge to archivists and media custodians. Unlike contemporary computer generated born-digital materials which usually only rely on specific software to be rendered – software dependency, the digital information created by MiniDisc recorders is embedded in a physical medium which requires both designated hardware and software to access, identify and readout the information – hardware and software dependencies. This characteristic of MiniDisc leads to a series of challenges for archivists interested in performing preservation treatments on MiniDisc materials:

[73] "Digital Preservation Handbook 2nd Edition," Digital Preservation Coalition, 2015, https://www.dpconline.org/handbook

- Obsolescence of MiniDisc players and software – Sony announced the ending of manufacturing MiniDisc devices in 2013 and discontinued technical support for the MiniDisc-designated software SonicStage in 2015.
- The highly proprietary media format of MiniDisc, including the ATRAC codec and the .oma wrapper of its audio files, leads to its heavy reliance on the equally high-proprietary software SonicStage for information readout. However, with the obsolescence of SonicStage, reading out information from MiniDisc becomes increasingly difficult.
- SonicStage is Sony's proprietary software which is only compatible with specific Windows operating systems. With nowadays rapid advancing pace of computer operation environment, keeping SonicStage function smoothly becomes another painstaking hurdle in digital preservation.

Facing the above challenges, general users of MiniDisc and media professionals have strived to develop various methods to regain access to the original audio information stored in MiniDisc.

MiniDisc Collections in Archival Organizations – A brief overview

Before delving into specific methods of retrieving digital contents from MiniDisc, it is worthwhile to take a general survey on the landscape of MiniDisc collections held in archival organizations. Here, the author focuses on archival organizations in the United States. These organizations include archives, libraries, museums and historical societies.

Online Computer Library Center (OCLC)'s ArchiveGrid, a portal that included over 5 million records describing archival materials, indicated in their statistics that there are approximately 35 archival organizations hold materials in MiniDisc format (Appendix 1).

MiniDisc media was widely used for recording oral history interviews, recordings of stage sound/performance footage, recordings of live events (e.g. lectures, exhibitions), radio programs recordings, and educational audiovisual materials.

Among these archives, some of them are made up of a majority of MiniDisc materials. In this case, MiniDisc media usually served as the major medium for recording oral history interviews. For example, at the Library of Congress of the United States, there is a collection called "Voices of Civil Rights Project collection, 2003-2006". This collection consists of oral history interviews, sound and video recordings, photographs and manuscript materials documenting memories of the 20th century civil rights movements in the United States. Among the 399 items of audio records, 266 of them are in MiniDisc format.[74] The "Remembering the 20th century: an oral history of Monmouth County, 1999-2000" held by Monmouth County Library in New Jersey is a collection consisting of 122 MiniDiscs exclusively. It is an oral history project that began since 1999.[75]

The New York Public Library holds an archive of Ping Chong, an American contemporary theater director, choreographer and video artist. Audio materials in this archive contain a number of MiniDiscs which captured the sounds of live theater performances.[76] At the Fales Library and Special Collections at New York University, the "Betty Fussell Papers" collection contains 7 MiniDiscs which are presumably recordings of her food research lectures.[77] Another type of contents captured by MiniDisc media are radio programs and footage

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[74] "Voices of Civil Rights Project collection (AFC 2005/015)," Archive of Folk Culture, American Folklife Center, Library of Congress, Washington, D.C. https://lccn.loc.gov/2012655454

[75] "Remembering the 20th century : an oral history of Monmouth County, 1999-2000," Monmouth County Library, New Jersey, https://www.visitmonmouth.com/oralhistory/

[76] "Ping Chong archive. Audio materials," Archives & Manuscripts, The New York Public Library, http://archives.nypl.org/rha/22117

[77] "Betty Fussell Papers; MSS 160," Fales Library and Special Collections, New York University Libraries, http://dlib.nyu.edu/findingaids/html/fales/mss_160/index.html

recordings. At Hoover Institute Library and Archives at Stanford University, MiniDisc items are included in their "Radio Free Europe/Radio Liberty broadcast records" (collection number 2000C120, date range 1951-2005). American radio broadcasting organization operating Radio Free Europe and Radio Liberty. Under the Cold War context, American radio broadcasting organization operated Radio Free Europe (RFE) and Radio Liberty (RL). Radio Free Europe broadcasted to audiences in Eastern Europe and Radio Liberty to audiences in the Soviet Union. The Sound Recordings series consists of broadcast recordings, monitoring recordings, off-air recordings, and music recordings. From the earliest days, all recorded sound produced or recorded by RFE/RL was captured by different media formats, first on 1/4 inch open-reel tape and since 1995 recordings were made on cassette tape, DAT (digital audio tape) and MiniDisc.[78]

Appendix 1 shows an overview of archives in the United States that hold MiniDisc materials in their repositories. This list proves the once popularity of MiniDisc among cultural institutions. What have not been included in this list are hundreds of media organizations, which, during the late 1990s and the 2000s, widely adopted MiniDisc for daily recording tasks. And MiniDisc was exceptionally popular in radio stations. MiniDisc's superior sound quality and portability of MiniDisc recorder-players made it a then ideal medium for recording outdoor or indoor interviews and live performances.[79] Andy Lanset, Director of Archives at New York Public Radio (WNYC), commented "the news department wanted something lightweight, digital and simple after they stopped using cassettes and they adopted MDs for their field recording. The news department also grew significantly during this period, so, more people, more MDs."[80]

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[78] "Radio Free Europe/Radio Liberty broadcast records," Hoover Institution Archives, https://oac.cdlib.org/findaid/ark:/13030/kt996nd6jz/
[79] Tim Brookes, "Remember MiniDisc? Here's How You Can Still Use It in 2020," How-To Geek, July 35, 2020, https://www.howtogeek.com/680363/remember-minidisc-heres-how-you-can-still-use-it-in-2020/
[80] Andy Lanset, email communication, October 16, 2020.

Without much doubt, over the years, MiniDisc as one of the popular audio media, has captured and stored valuable historical audio information. But as MiniDisc becomes an obsolete media format, it is time for archivists and media custodians to mind their discs.

MiniDisc Communities

Despite the obsolescence of MiniDisc technology, people's fondness towards this media format has not yet vanished. Rather, Internet-based communities of MiniDisc fans are still active across the world. These communities are made up of professional technicians, amateur MiniDisc technology enthusiasts, former and current MiniDisc users, and those who are interested in this "vintage" media format.

"minidisc.org" is an online portal that is regarded as the "one-stop shop" of MiniDisc – it gathers and integrates a large amount of information about MiniDisc technology, MiniDisc equipment, users' reviews, press reports, and an online forum for MiniDisc-related discussion. On social media, global MiniDisc fans groups are easily found. For example, Facebook group "MiniDisc" was established in 2008. The number of its members now reached over 4,300. People not only shared MiniDisc information in the community, but also take part in different sorts of online events to exchange views on sonic technology.[81] "MiniDisc Global Forum (English)" is another active MiniDisc fans community on Facebook, also established in 2015 and with over 2,000 members. Group members showcase their MiniDisc media and equipment collections, ask questions about MiniDisc hardware and software (e.g. SonicStage installation), and, more importantly, provide mutual-aids to solve technical problems.[82] Facebook group

[81] "MiniDisc," Facebook private group, https://www.facebook.com/groups/minidiscgroup
[82] "MiniDisc Global Forum (English)," Facebook private group, https://www.facebook.com/groups/1493354177631766/about

"Minidisc repair" was established in 2015. It has over 2,000 group members who vigorously share information and experience on troubleshooting MiniDisc technical issues, especially in terms of DIY (do-it-yourself) MiniDisc equipment repair.[83] MiniDisc communities also appear in another popular social media site – Reddit. For instance, "The last users of MiniDisc" Reddit group was founded in 2010 and now has over 2,600 members.[84]

Though most of the MiniDisc enthusiasts on these forums are general music consumers who only intend to successfully make their own mixtapes and keep their MiniDisc equipment functional, their versatile experience and information sometimes could become useful resources to AV archivists.

Non-Archival Trials of Retrieving MiniDisc Audio Information

With the existence of many still active MiniDisc communities, different methods of transferring MiniDisc contents are not difficult to find on the Internet; however, many of these methods are simply for the purpose of saving recorded audio content, rather than for archival preservation. Therefore, when discussing these non-archival approaches, people seldom pay attention to file format or other digital audio file related technical specifications (e.g. bit rate, sampling rate).

In this realm of non-archival approaches, there are three typical directions:

1. Directly recording audio tracks from personal computers to MiniDisc recorders by wiring the two with a headphone jack;
2. Connecting MiniDisc player (NetMD or Hi-MD) to personal computer via proprietary SonicStage under the software's designated operating environment;

[83] "Minidisc repair," Facebook public group, https://www.facebook.com/groups/729751677160254/about
[84] "The last user of MiniDisc," Reddit group, https://www.reddit.com/r/minidisc/

3. Connecting MiniDisc player (NetMD or Hi-MD) to personal computer via an open-source interface which is built on open-source coding resources.

The first approach is a simple how-to, and the model of the MiniDisc player does not matter as long as it could play the audio tracks. An instruction for this approach could be found at "How to Transfer a Minidisc Recording to a Computer" by Abraham Hovey.[85]

The second approach is regarded as a more intricate one. As mentioned at the beginning of this chapter, originally, Sony had its MiniDisc users connect their players with personal computers via the proprietary software SonicStage. SonicStage, theoretically, could only operate under a Windows system (system versions before Windows 10). Unlike MP3 players which could be immediately recognized by personal computers (Windows, Mac or Linux system), MiniDisc players could not be detected without having SonicStage installed and functional. For users of a Mac system or an advanced Windows system, having the SonicStage installed is an inevitable hurdle.

In this regard, one of the most widely adopted methods is installing and running SonicStage under an emulated environment. For example, YouTuber Gear Seekers shares a follow-along instruction on how to use VMware – an emulation machine to emulate the Windows 7 operating system in order to install and operate SonicStage.[86] Some MiniDisc users, however, explored alternative methods to activate SonicStage in a Windows 10 environment, while users' reviews on these methods varied.[87]

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[85] Abraham Hovey, "How to Transfer a Minidisc Recording to a Computer," ItStillWorks, Sept 22, 2017, https://itstillworks.com/12271106/how-to-transfer-a-minidisc-recording-to-a-computer

[86] Gear Seekers, "HOWTO Sony NetMD Minidisc Players in Windows 10 (MZ-N505)," YouTube video, July 9, 2018, https://www.youtube.com/watch?v=OE1e7rAzgSI

[87] For example, see Michael Kachuk, "Guide to getting your Net MD Walkman working on Windows 10," MiniDisc, Sony Insider Forums, Jan 22, 2018, http://forums.sonyinsider.com/topic/29620-guide-to-getting-your-net-md-walkman-working-on-windows-10/ ; "NetMD for Windows10?," discussions in "Discmans, Minidisc, DCC and other players" section in stereo2go.com forum, Aug 6, 2019, http://stereo2go.com/forums/threads/netmd-for-windows10.4692/?fbclid=IwAR31pxvg1607Y_-mC9uEqDKou1ms21tqTU45mQ33y6zBsDHk_dKAnYDPeeA

The third approach makes use of open-source applications to avoid the hassles caused by SonicStage. In addition, this approach allows MiniDisc players to connect to several operating systems (Windows, Mac and Linux) without going through an emulated process. This open-source approach has been widely recommended by MiniDisc users in social media communities. In the next chapter of the thesis, more discussion and documentation of the author's testing results will be elaborated.

For general users, Web MiniDisc Project – a web-based MiniDisc content management interface is, so far, the most convenient and straightforward tool.[88] To activate the Web MiniDisc Project, users simply need to visit https://stefano.brilli.me/webminidisc/ via Google Chrome and get the MiniDisc player (NetMD or Hi-MD) connected with the computer via a USB cable. Once the player is securely hooked with the computer, the contents stored in the MiniDisc media will be shown on the computer screen. From there, users can manage the existing contents (e.g. rename, re-order) and import new contents into the MiniDisc from the computer. But this Web MiniDisc Project does not allow exporting digital files from MiniDisc players to computers. The Web MiniDisc Project is made possible based on other open-source resources such as FFmpeg[89] (for reading audio files) and linux-minidisc[90] (a set of codes).

Another open-source tool recommended by MiniDisc community members is a project called "Platinum-MD", which is also based on the coding sets written in the linux-minidisc project. Platinum-MD is a graphic-user-interface (GUI) for NetMD.[91] It allows two-way transfer of audio information between personal computer and MiniDisc player.

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[88] See Tim Brookes
[89] An open-source command-line based application for decoding, encoding, transcoding, muxing, demuxing, streaming, filtering and playing audiovisual files in various formats. See https://ffmpeg.org/
[90] Refer to John Glaubitz, "linux-minidisc," Github page, https://github.com/glaubitz/linux-minidisc
[91] Refer to Gavin Bender, "Platinum-MD," Github page, https://github.com/gavinbenda/platinum-md.git

For users with a MZ-RH1 model Hi-MD, the project "NetMDPython" could serve as an alternative solution. This is also a project based on codes from linux-minidisc and FFmpeg. "NetMDPython is a collection of Python scripts which allow users to control NetMD devices on Linux, Unix and MacOS … With NetMD Python, you can upload tracks from standard MDs with the help of the MZ-RH1 Walkman to your PC, list the contents of any standard MD with any NetMD device and control and record tracks over analog input with any NetMD device."[92]

Archival Approaches of Retrieving and Archiving MiniDisc Audio Information

Over the years, in cultural institutions across the world, AV archivists and media lab professionals have tried to reveal and preserve audio information stored in MiniDisc – a media that was once believed to be an ideal form for keeping superior quality audio sounds securely in its finely crafted optical disc locked inside the tiny plastic case. As commented by Isaac Hart who handled MiniDisc content transfer at the Manchester Central Library,

"Once the company that produced these devices no longer manufactures them, or stops supporting the software used to operate them, the only means left available to recover the sounds held within is through cannibalising existing machines or running emulators, software that recreates an older operating system on a newer interface. The process of archiving digital copies of these recordings is an at times painstaking and laborious process, but it is also an urgent one because optical discs can be fragile, and are very susceptible to damage from light and handling."[93]

[92] Refer to https://wiki.physik.fu-berlin.de/linux-minidisc/doku.php?id=netmdpython
[93] Isaac Hart, "From Disc to Digital: MiniDisc Transfer," North West Sound Heritage, Apr 16, 2020, https://northwestsoundheritage.org/2020/04/16/from-disc-to-digital-minidisc-transfer/

Unlike those above-mentioned music lovers who care most about how to create and play their favorite MiniDisc albums and how to keep their players functioning well, archivists as well as those providing archival-level media transfer services not only retrieve the digital contents in MiniDisc storage, but also need to manage their correspondent metadata, catalogue digital objects, and create derivatives out of the original format for external access.

In this section, the author documents some existing workflows of handling MiniDisc media collections in an archival setting or adopted by media professionals who provide media transfer services to cultural institutions. However, it is found that, different from the varying approaches adopted in the non-archival MiniDisc community, according to the author's interviews with AV archivists and media professionals, the proprietary SonicStage-reliant workflow is commonly preferred among archives and media labs. While some take an emulation machine approach, others choose to maintain a legacy operating system. Lately, with more applications developed by computer engineers, some organizations run SonicStage in the latest Windows environment by installing supplementary drives. Interestingly, the British Library Sound Archives has gone through all these phases. Besides the SonicStage-reliant workflow, a more straightforward and software-free approach is also adopted by some organizations: they directly wire a MiniDisc deck to a computer.

A "legacy" approach – Keep the old wheel running

When searching preservation projects of MiniDisc on the internet, an oral history project by The British Library is a noticeable one. As the situation in the United States, in the heyday of the MiniDisc format, this media format was "arguably found more favour as a recording medium, particularly among broadcasters (and oral historians)".[94] A BBC (British Broadcast Corporation) oral history project called "The Century Speaks: Millennium Oral History Project" is comprised of more than 6,000 MiniDiscs recording the voices of thousands of people from all walks of life. This project was created by BBC local radio stations across the country during 1998-1999. This large number of MiniDiscs is currently held by The British Library as the collection "The Millennium Memory Bank project".[95] In a video featuring Gosha Shtasel, Preservation Audio Engineer at the British Library Sound Archives, he demonstrated what used to be the workflow of retrieving MiniDisc contents at the British Library: A legacy Windows XP operating system was maintained in the lab for running SonicStage. A Sony MZ-RH1 model of MiniDisc recorder-player (a Hi-MD model) is utilized for playing-back and reading audio tracks from MiniDisc media.[96]

New York Public Radio (WNYC) took a similar direction. Their Director of Archives, Andy Lanset introduced that they have the SonicStage installed and operated in an off-network Windows 7 system, which has been intentionally kept and maintained in the lab for legacy software. Digital contents stored in MiniDisc media are exported to the local computer through SonicStage. Originally, SonicStage directly converted the raw ATRAC-compressed audio tracks into .wav format before exporting them to the local directory. But recently, archivists found that this direct conversion is no longer performed by the software, and they have to use different software to convert the ATRAC files to .wav format for long-term preservation.[97]

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[94] Steve Cleary, "The MiniDisc revival starts here (maybe)," Sound and vision blog, The British Library, Sept 7, 2018, https://blogs.bl.uk/sound-and-vision/2018/09/the-minidisc-revival-starts-here-maybe.html
[95] "Millennium Memory Bank," C900, The British Library Sound and Moving Image catalogue
[96] Paul Maclean, "British Library: Saving MiniDisc," YouTube Video, Mar 31, 2020, https://youtu.be/mKjWbzA-xP0
[97] Andy Lanset, personal interview via email, January 14, 2021.

An emulation approach

Slightly different from the WNYC "traditional" approach, the Stanford Media Preservation Lab goes a slightly twisted way by implanting a virtual machine. During an interview, Geoff Willard, Media Production Coordinator at the Stanford Media Preservation Lab explained how they handled MiniDisc collections in an emulated environment.[98]

The computational environment in the Lab is MacOS machine with VMWare Fusion running an instance of Windows XP.[99] The lab purchased a Sony MZ-M200 model MiniDisc player (a Hi-MD model)[100] in February 2011 for managing MiniDisc collections. The SonicStage (version 4.3 Ultimate edition) which came along with the MZ-M200 player package was installed in the virtual machine. The digital audio files in .oma format (the original ATRAC-encoded format) are extracted. The detailed workflow at the Stanford Media Preservation Lab could be found in Appendix 2.

Most of the MiniDisc media processed in the Lab come from the Stanford University archive and the Hoover Institute archive. Curators at these archives prioritize media transfer tasks and send them over to the Lab. So far, what has been processed in the Lab are mostly standard-play MiniDiscs.

Running SonicStage on a virtual machine was also the approach adopted by the British Library – an emulated Windows XP was operated to support SonicStage. What's more, to accelerate the transfer efficiency, they had four virtual machines running at the same time, so

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[98] Geoff Willard, personal interview via email and video chat, January 6 & 14, 2021.
[99] VMware Fusion Pro and VMware Fusion Player Desktop Hypervisors are virtual machines that provides Mac users the capability to run Windows on Mac along with other operating systems. Usage fee of VMware varied based on the user's nature. See https://www.vmware.com/products/fusion.html
[100] The MZ-M200 is the Hi-MD model with most of its technical specifications as the same as those in MZ-RH1. The only different is that the package of MZ-M200 comes with a stereo microphone.

that four MiniDisc Walkmans were connected to the computer and four MiniDiscs were able to be transferred at one time.[101]

A driver-supplemented approach

The North West Sound Project based in the United Kingdom, on the other hand, takes an alternative approach by running the legacy SonicStage in a latest computer operating system. At the Manchester Central Library are boxes of MiniDiscs that contain oral history interviews with South Asian immigrants living in West England. These MiniDisc media represent the most original audio records of these interviews which were made in the early 2000s.

At the Manchester Central Library, a Sony MZ-RH1 model MiniDisc recorder-player (a Hi-MD model) is used for playing-back MiniDisc media. Originally, the version 4.3 SonicStage software was operated in an emulated Windows XP system for handling MiniDisc files – the same approach as the Stanford Media Lab. But in recent years, they changed the workflow, and the SonicStage software is made to be installed and operated in the latest Windows 10 computer environment. This is a significant jump because it is no longer necessary for archivists to switch between different operating systems. To facilitate this, a Net MD driver (a 64-bit one for Windows 10 in this case) is installed to "allow the twentieth-century minidisc recorder to talk to your present-day PC."[102] The recent versions of Windows operating systems (Windows 10, 8, 7 and Vista) are run on a 64-bit version. But MiniDisc players are not equipped with a 64-bit driver. Therefore, an extra driver is needed. After the digital contents are transferred to the local

[101] Gosha Shtasel, personal interview via video chat, April 16, 2021.
[102] Isaac Hart, "From Disc to Digital: MiniDisc Transfer"

computer, quality-control (QC) process will be conducted.[103] Different from the Stanford Media Lab, the Manchester Central Library tended to extract audio files in .wav format as SonicStage offers this auto-conversion function. The thorough MiniDisc handling workflow adopted by the Manchester Central Library can be found in Appendix 3[104].

Similarly, the British Library Sound Archives beginning in late 2018, also transitioned to this approach: a NetMD Driver (64-bit) was installed in the Windows 10 operating system in order to operate the SonicStage (4.3 ultimate version software). In order to archive audio files in a more widely adopted format than a highly proprietary one, the British Library transfers audio files from MiniDiscs to computers by commanding SonicStage to convert the files into the .wav format. If an audio recording is chunked into different files, concatenation before ingesting into the library system is also needed.[105] [106]

The MediaPreserve - An Audiovisual Laboratory (hereafter The MediaPreserve), which is based in Pennsylvania, the United States, also employs this workflow. The MediaPreserve, as a digitization and media transfer service provider, serves a variety of archival entities, such as those based in universities, public libraries, and museums. The MediaPreserve uses the Sony MZ-RH1 MiniDisc player for digital contents retrieval. This MiniDisc player is the same model as some of the above-mentioned organizations. As a best practice, the studio engineer takes pictures of each physical media before the actual content transfer process. Unless substantial dirt is found on the disc surface, they seldom need to clean a physical disc, as the optical disc which

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[103] A follow-along instruction of 64-bit driver installation could be found at "64 bit driver for Sony NetMD (Net MD) and standard MiniDisc for 64 bit versions of Windows 10, Windows 8, Windows 7 and Windows Vista," archivisiondirectory.blogspot, 2010, https://archivisiondirectory.blogspot.com/2010/10/64-bit-driver-for-sony-netmd-net-md-and.html

[104] The workflow is from Isaac Hart, "From Disc to Digital: MiniDisc Transfer" and from an interview with Isaac Hart via Facebook communication was conducted on January 18, 2021.

[105] Gosha Shtasel, personal interview.

[106] Gosha Shtasel, "Save our Sounds – Unlocking our Sound Heritage MiniDisk Format (version 1)", The British Library Sound Archives internal document, July 2, 2020.

stores the digital contents is tightly embedded in the plastic case. SonicStage 4.3 is run on computers with Windows 7 and 10 operating systems, which are what they use in the studio. Once the audio tracks are recognized by the software, SonicStage gives options to keep the tracks as ATRAC files or convert to another format. At The MediaPreserve, they have SonicStage set to convert the tracks to.wav files at 16 bits and 44.1 kHz for clients to ensure it can be played in any media player they are using. After the transfer process, the studio engineer will QC the files through spot-checking. If no obvious errors are detected, the files will be moved to the QC engineer, who runs them through Dobbin QC software, which will provide a list of possible errors detected. The QC engineer will also listen to the files a second time to determine if the errors detected by the software are issues that would require a studio engineer to re-play that disc.[107]

From the above documentation, it is evident that Hi-MD models are chosen for playing back MiniDisc media. As mentioned in the previous chapter, Hi-MD is the system that features the most robust backward compatibility. With a Hi-MD model in the organization, archivists have greater flexibility to conduct MiniDisc file transfer. A relatively new version of SonicStage software – the version 4.3 is also adopted by different institutions.[108] In addition, for archival purposes, the digital files transferred from MiniDisc media to local computer directory are usually catalogued and QCed. Raw files and access files are created to serve different archival purposes. Multiple tracks belonging to the same event are joined into a single file for easier access, as providing access of archival records to the public is one of the goals of archival organizations. Figure 12 demonstrates a general workflow adopted by archival organizations and

[107] Laura Russak, personal interview via email on January 20, 2021.
[108] The last version of SonicStage is version 5. But its compatibility is less robust as the version 4.

archival-standard media labs for retrieving and archiving audio information stored in MiniDisc media.

However, based on the workflows described above, different organizations choose to keep the audio files extracted from MiniDiscs in different formats. While some organizations incline to keep the .oma files, others choose to convert the files into a more commonly used .wav format. In the next chapter, the author is going to experiment different approaches of retrieving and archiving MiniDisc contents. Further exploration of different file formats will be discussed as well.

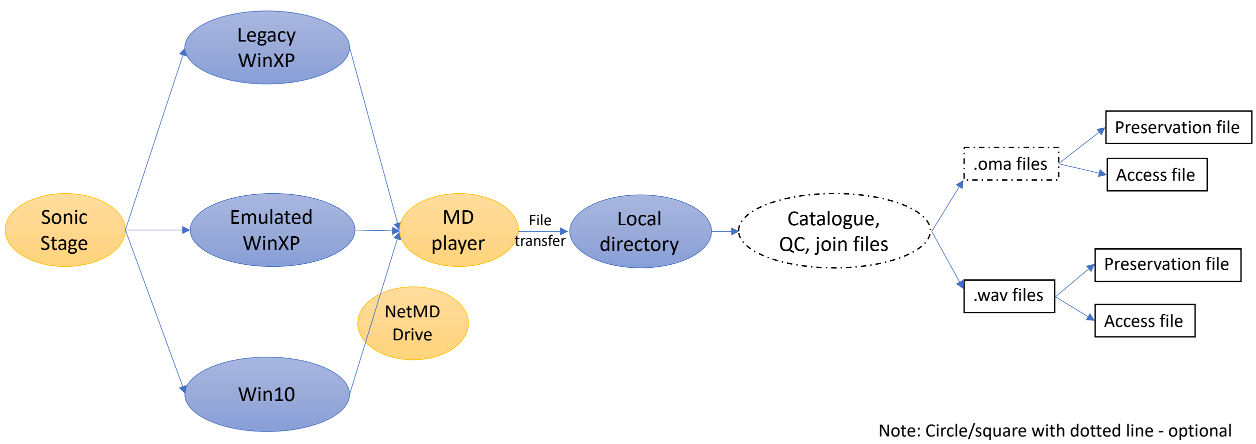

Figure 12. General workflow adopted of archival organizations and media labs

A deck wiring approach

Noticing the risk brought by proprietary software, such as discontinuing support from developers or incompatibility with the latest computer operating system, some organizations, along with a SonicStage-reliant workflow, also incorporate deck-wiring methods to extract audio information from MiniDisc. The MediaPreserve is one among them.

At The MediaPreserve, a Sony MDS-B6P player is used for this approach. The Sony MDS-B6P is a professional deck introduced in 1997.[109] When tracks fail to be identified or extracted in SonicStage, the MiniDisc media will be played on the deck. The digital audio signal will be transferred via the AES Output, which is directly connected to the AES card in the computer. Instead of SonicStage, in this approach, they record the tracks to .wav format at 16 bits and 44.1 kHz file through a professional audio-editing software called Cubase. For the QC process, if a MiniDisc is played back using the MDS-B6P, the studio engineer is able to listen to the file as it plays in real time and note any issues that may be inherent on the discs. These files also go through the same process with the QC engineer as stated above.[110]

The Stanford Media Preservation Lab also sets aside a MiniDisc deck for MiniDisc transfer. Tascam MD02B MD Player is the model they use in the lab. Audio information is transferred via the S/PDIF digital outlet from the deck to the Denon DN-F650R, a professional solid-state recorder. By doing this, the recording process could bypass any computer or software. However, according to Geoff Willard, this wiring approach was only used once in the lab.[111]

From the above documentation, it is evident that the Sony proprietary software SonicStage is still the tool that archival organizations and media labs rely on the most. It is also not difficult to tell, from the interviews with media technicians and archivists, how the risks of using SonicStage remain, as they have to garner various methods to "tame" the software, whether be maintaining an Internet-off old computer in the lab or finding an extra drive to keep the software up to date. In addition, as the cases of The MediaPreserve and the Stanford Media Preservation lab show, back-ups are prepared to rescue contents that are left behind by

[109] For more detailed specifications, see "Sony MDS-B5/B6P," minidisc.org, http://www.minidisc.org/part_Sony_MDS-B5+B6P.html
[110] Laura Russak, personal interview.
[111] Geoff Willard, personal interview.

SonicStage. Taking all these into consideration, it is time for archivists to not only mind their MiniDiscs, but also mind their SonicStage. Therefore, in the next chapter, besides the SonicStage-reliant and the deck wiring approaches, the author will introduce an alternative approach for retrieving contents from MiniDisc – a route grounded on tools that are non-proprietary and open-source.

Chapter Four: Retrieving and Archiving MiniDisc Contents – Lab experiments

Based on the existing resources and workflows employed by media professionals, the author experimented with different approaches of retrieving and archiving digital contents originally stored in MiniDiscs. This chapter provides systematic documentation of the experiences and processes carried out during those experiments. The experiments and instructions illustrated in this chapter are mainly designed to meet archival goals and purposes.

As reviewed in the previous chapter, AV archivists and media technicians have widely adopted the approach which heavily relies on the proprietary SonicStage. To achieve this, either keeping a legacy computer system running or emulating the legacy operating system is required to get the equally legacy SonicStage installed and functioning. In order to test the feasibility and efficacy of this approach, the first part of this chapter will document the author's own experiment of emulating the Windows XP system, installing the widely recommended SonicStage version 4.3 software and ripping out MiniDisc tracks recorded in different modes for preservation.

However, the SonicStage approach involves multiple steps of operation and multiple tools to be installed and maintained, leading to a higher probability of unexpected hassles and troubles. As computer operating systems and their dependent appliances advance rapidly, it is increasingly difficult to keep everything seamlessly compliant to the legacy software which was originally designed for one particular operating system only. In addition, due to the highly proprietary nature and the obsolete status of SonicStage – Sony no longer provides software support, making reliance on this software a problematic and unsustainable solution to users who hope to manage the digital contents stored in MiniDisc media and preserve them for long-term usage. In the archival world, with huge quantities of audiovisual collections in MiniDisc format waiting to be transferred to a more up-to-date format for long-term preservation, it is of crucial importance that archivists envision more sustainable and better maintained workflows handling MiniDisc collections.

Therefore, in the second part of this chapter, the author will introduce an approach which bypasses both the operating system emulation and the SonicStage software – an open-source coding-based approach of managing and retrieving digital contents stored in MiniDiscs. This open-source-reliant approach is also the one in which the author devoted the most effort in investigating available resources and experimenting with trials and errors. Contrary to the Sony proprietary SonicStage, open-source tools for managing MiniDisc contents are developed and maintained by a group of computer engineers who are willing to make their source codes publicly available and are ready to offer assistance to users in need. The discussion below, based on the author's own experiments, aims to provide a comprehensive documentation and follow-along instructions for archivists and media preservationists in their future daily archival work. It is important to note that, the open-source approach does not require any cost spent on hardware or software as the SonicStage-reliant and the deck wiring approaches do, but only light experience on command-line working environment is needed.

Following the open-source approach is the documentation of experiments of the deck wiring approach – a relatively traditional and "analog" route to transfer audio information from its original media. The advantages of the deck wiring approach include avoidance of getting into computer software failures and reduction of archivists' anxiety of the need to harness computational applications, command lines and codes. But this deck wiring approach transfers MiniDisc audio contents from a deck to a personal computer in an analog way, which is similar to real-time music recording. Hence, the audio information retrieved by this means is far from a bit-by-bit duplication of the original information recorded in the disc, but a capture of the projected sound. Since audio contents originally recorded in MinDisc are born-digital and the MiniDisc deck utilized by the author is equipped with a digital outlet, in this thesis, the deck wiring approach of retrieving MiniDisc contents was completed via digital signal transfer.

Basically, the list of hardware equipment used by the author to conduct the below experiments is as below:

- iMac (macOS Catalina version 10.15.7)
- Sony MZ-M200 Hi-MD recorder-player (an equivalent to MZ-RH1, the latest MD Walkman model released by Sony) (Figure 13)
- USB 2.0 port to connect MD player with Mac
- One MiniDisc formatted as standard MD with audio tracks recorded in SD, LP2 and LP4 modes (tracks are voice sound recorded via microphone)
- One MiniDisc formatted as Hi-MD with audio tracks recorded in Hi-MD PCM, Hi-SP and Hi-LP modes (tracks are voice sound recorded via microphone)
- Several mixtape MiniDiscs the author made via SonicStage in the early 2000s
- Several pre-recorded commercial MiniDiscs (standard MD format)

Figure 13. Sony MZ-M200 MiniDisc recorder-player and some MiniDisc media

SonicStage-Reliant Approach

Emulation is rarely seen as an innovative approach among personal computer users (especially the gaming community and the information technology industry. Emulation is a technique for implementing a virtual machine on a host computer whose instruction set is different from the host computer's.[112] Today, emulation has been proven to be an effective technique for preserving legacy digital artefacts. In the case of MiniDisc, emulation has been employed by different media labs and cultural institutions to preserve the legacy Sony SonicStage software, which, ultimately, is used for managing and retrieving digital contents stored in MiniDisc media.

In terms of the use of emulator, VMware is a commercial emulation widely used among general and professional computer users, which is also adopted by the Stanford Media Preservation Lab. But to conduct the experiment for this thesis project, the author applied the Oracle-developed free-of-charge emulator VirtualBox. In terms of SonicStage, the 4.3 Ultimate

[112] David Rosenthal, "Emulation & Virtualization as Preservation Strategies," 2015, https://mellon.org/media/filer_public/0c/3e/0c3eee7d-4166-4ba6-a767-6b42e6a1c2a7/rosenthal-emulation-2015.pdf

version is recommended by archivists and media technicians as well as many general MiniDisc users active in Facebook communities. Therefore, this is also the version of SonicStage applied by the author for this thesis project. As Sony no longer supports SonicStage and thanks to the generous contribution by many MiniDisc hobbyists, an intact disk image of SonicStage 4.3 Ultimate version installation package (in .iso format) is available for free download on the Internet Archive. Because SonicStage 4.3 Ultimate versions runs in Windows XP operating system, a Windows XP installation package (disk image in .iso format) is also needed for this experiment.

In addition to the hardware equipment listed before, these are the applications specifically prepared for the SonicStage-reliant approach:

- Windows XP installation package disk image (in .iso format)
- SonicStage 4.3 Ultimate version (download from Archive.org)
- Virtualizer "VirtualBox" (version 6.0) by Oracle[113] installed in the host Mac OS system

General workflow and results

First, the author installed the VirtualBox and its extension pack.[114] Following that, the author navigated to install the Windows XP operating environment in the virtual machine.[115] During this process, it is important to ensure the free-to-use storage capacity in your host computer is sufficient enough to host the guest system.

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[113] VirtualBox is a general-purpose full virtualizer for x86 hardware, targeted at server, desktop and embedded use. See "About VirtualBox," VirtualBox, https://www.virtualbox.org/wiki/VirtualBox
[114] Download available here https://www.virtualbox.org/wiki/Downloads
[115] For a step-by-step instruction guide, see "Installing WindowsXP on Oracle VM VirtualBox," Packtpub, https://subscription.packtpub.com/book/networking_and_servers/9781782163589/1/ch01lvl1sec09/installing-windowsxp-on-oracle-vm-virtualbox

Second, the author installed the SonicStage 4.3 Ultimate version software into the emulated Windows XP system. With SonicStage being installed, once a MiniDisc player is connected to the computer via a USB 2.0 port, SonicStage is able to detect the device and audio tracks stored in the MiniDisc media are shown on the SonicStage interface.

Third, for archival purposes, archivists may want to extract audio tracks from MiniDisc media in as faithful to their original states as possible. To achieve this, it is crucial to perform certain configurations. Once all the settings are tuned accordingly and the importation destination directory is assigned, the transfer process can commence (For detailed instructions, see Appendix 4).

Fourth, since the whole transfer process is performed in the emulated environment, the extracted audio tracks need to be transported back to the host system for further scrutinization and preservation treatments. Either setting a shared folder between the guest and the host system or transporting the files via a portable USB drive is a feasible transportation route.

As a result, the whole process of MiniDisc audio information transfer performed by SonicStage with the Sony MZ-M200 is efficient and easy-to-handle. Audio tracks are exported as .oma files with the ATRAC3 or PCM codecs.

But having SonicStage carry out the transfer is by no means without challenge, even all settings are tuned correctly. First, it is important to note that, audio tracks in protected mode are not able to be transferred to personal computers even via SonicStage. As mentioned above, chances are these protected tracks were originally imported into MiniDisc media directly via SonicStage, which is automatically embedded with an information encrypted mechanism to prevent commercial tracks being pirated. Therefore, for the purpose of conducting the experiment, the author recorded some audio tracks in different modes even within one disc.

These tracks were recorded via a microphone instead of via SonicStage. For example, in the standard formatted MiniDisc, tracks were recorded in SP, LP2 and LP4 modes. According to the technical parameters of MiniDisc published by Sony, audio information recorded in SP and LP2/4 modes is supposed to be encoded with different codecs – ATRAC1 and ATRAC3 respectively. However, after transfer, the SP-mode audio track is converted to ATRAC3 codec wrapped in .oma, instead of keeping the original ATRAC1 codec. It seems that SonicStage still performs conversion in the process of transfer. Interestingly, for tracks recorded in Hi-MD lossless PCM mode, the PCM codec (wrapped in .oma) remains the same after transfer.

Figure 14 shows the MediaInfo-generated technical metadata of the audio track (SP-mode recorded) after SonicStage transfer. In comparison, Figure 15 shows the FFprobe-generated technical metadata of the audio track (SP-mode recorded) transferred via open-source command-line tool NetMDPython (more discussion in next section). It is found that, the same audio track is encoded differently when being transferred by different tools. While SonicStage encoded the track into ATRAC3 (wrapped in .oma), the open-source tool NetMDPython seems to retain the original ATRAC1 codec (wrapped in .aea) of the audio track.

Though the engineering mechanism of SonicStage is beyond the discussion scope of this thesis, the above findings are worth extra attention and further investigation from archivists and media technicians if they hope to preserve MiniDisc audio information in its most original state.

```
Complete name                            : /Users/klavierwong/Downloads/Test2-SPMD_VM/001-SP.oma
Format                                   : OpenMG
File size                                : 1.00 MiB
Duration                                 : 30 s 840 ms
Overall bit rate                         : 273 kb/s
Album                                    : Transferred from MD (2021-02-09 11:42:08)
Track name                               : SP

Audio
Format                                   : Atrac3
Format/Info                              : Adaptive Transform Acoustic Coding 3
Duration                                 : 30 s 840 ms
Bit rate                                 : 256 kb/s
Channel(s)                               : 2 channels
Channel layout                           : L R
Sampling rate                            : 44.1 kHz
Compression mode                         : Lossy
Stream size                              : 965 KiB (94%)
Encryption                               : SDMI
```

Figure 14. MediaInfo-generated technical metadata of SP-mode track after SonicStage transfer

```
Input #0, aea, from '/Users/klavierwong/Downloads/Test2-SDMode-01262021-transferCLI/03 - SP.aea':
  Duration: 00:00:32.72, bitrate: 292 kb/s
    Stream #0:0: Audio: atrac1, 44100 Hz, stereo, fltp, 292 kb/s
```

Figure 15. FFprobe-generated technical metadata of SP-mode track after NetMDPython transfer

Open-Source Approach

The experiments conducted by the author are based on the existing coding scripts and software developing efforts put forth by projects of “linux-minidisc”, “QHiMDTransfer”, “NetMDPython” and “Platinum-MD”. These projects are accomplished by a group of computer engineers who reverse-engineered Sony’s proprietary media format and software to develop and update MiniDisc tools compatible to different operating systems and the latest computing environment.

In addition to the stated above hardware equipment (iMac, MZ-M200 player, USB port), the author also has Homebrew and FFmpeg installed in the iMac OS system. But other than these two, no additional specific hardware or software is needed.

The "linux-minidisc" project is established by a group of computer engineers and software developers who are dedicated to collecting as much information as possible regarding NetMD/HiMD hardware in order to get it to work on different computational operating systems including Windows, MacOS, Linux and so on.[116] As stated in the linux-minidisc project website,

"We want to create a simple transfer software for HiMD and NetMD walkman which will run under our preferred operating systems and is free of any of the annoying 'features' of the original software. Unlike iPods or other well-known portable MP3 players, Sony MD devices employ a highly secured and encrypted storage and transfer system of the audio data, which makes an understanding and implementation of software for these Sony models much more difficult. However, thanks to the stubbornness of some guys on the net, there has already been some progress in understanding the Sony software."[117]

The "linux-minidisc" project is also a foundation based on which a growing number of open-source applications, including the NetMDPython and Platinum-MD software are developed.

Even though not being a software developer or computer engineer, the author often gets involved in the linux-minidisc community's discussion by sharing user experience and help seeking. As the source codes and the derivative tools under the linux-minidisc umbrella are actively maintained by a group of engineers and the community of general MiniDisc users is global and large-scale, idea exchange is robust and technical questions are always answered promptly.

Under the umbrella of linux-minidisc project are a number of open-source tools:

---

[116] "linux-minidisc," linux-minidisc, https://wiki.physik.fu-berlin.de/linux-minidisc/doku.php?id=start#linux-minidisc
[117] See "linux-minidisc," linux-minidisc

- NetMDPython - a collection of Python scripts which allow the control of NetMD devices on different operating systems. With NetMD Python, users can upload tracks from standard MDs with the help of the Sony MZ-RH1/M200 Walkman to their personal computers, list the contents of any standard MD with any NetMD device and control and record tracks over analog input with any NetMD device.[118] Usage of NetMDPython is in the command-line environment.
- QHiMDTransfer – a tool with graphic-user-interface (GUI) to manage digital contents recorded in Hi-MD modes. It is supposed to be a simple clone of the Mac OS X software "HiMD Music Transfer for Mac 2.0" which is a product developed by Sony in 2006 along with the launch of MZ-RH1/M200 MiniDisc Walkman.[119] With QHiMDTransfer, users could transfer digital contents recorded in Hi-MD modes to their personal computers.
- Platinum-MD – a project conducted by Gavin Benda out of his personal interest, instead of by a linux-minidisc developing member. But Platinum-MD is also a software built on the source codes of linux-minidisc. It was at first designed to be a GUI for NetMD device, aiming to make uploading audio files to NetMD players seamless and automatic.[120] With the latest released Platinum-MD, users are able to not only transfer digital contents from their computers to MD device, but also the other way round. Platinum-MD was originally NetMD-compatible only, but the latest release tries to incorporate compatibility with certain models of Hi-MD.
- Web-minidisc – a web-based application aims to bring NetMD devices to the web.[121] This is also a project made possible with the foundation source codes laid by the linux-minidisc project. But this web-based tool could only allow users transferring audio tracks from their

[118] "NetMDPython," linux-minidisc
[119] "QHiMDPython," linux-minidisc, https://wiki.physik.fu-berlin.de/linux-minidisc/doku.php?id=qhimdtransfer
[120] Gavin Bender, "Platinum-MD"
[121] "Web-minidisc," web-minidisc homepage, https://stefano.brilli.me/webminidisc/

computers to MD players, not the other way round. Therefore, it is more designed for general MiniDisc users instead of for archival purposes.

General workflow and results

For the purpose of this thesis, the open-source experiments were mainly conducted with "NetMDPython", "QHiMDTransfer" and "Platinum-MD", because they all support bi-directional audio information transfer between MiniDisc players and personal computers, and all of them are able to retrieve audio contents from MiniDisc players in ATRAC codecs. The general workflow of applying the open-source approach is as shown in Figure 16. Detailed documentation of the author's lab experiments, follow-along instructions of the above mentioned open-source codes and tools, and the results of working with different tools are recorded in the author's GitHub project page which is open for public access and commentary.[122]

Figure 16. General workflow of working in open-source coding approach

However, some issues are still discovered when experimenting with the above-mentioned open-source tools. First, due to the fact that there are still under-developing and under-testing elements emerged from those MiniDisc projects, some functions are only available to certain models of MiniDisc players or audio tracks recorded in certain modes are in usage. Generally speaking, Sony's MZ-RH1/M200 is the most versatile and effective device to work with all the

[122] "MD-Project," the author's GitHub MiniDisc project page, https://github.com/jyw321/MD-Project

open-source tools developed under the umbrella of linux-minidisc. But it is worth more trial and errors to determine if other models can be used in a similar fashion. Second, in this approach, only unlocked audio tracks are able to be transferred using the open-source approach. If audio tracks were originally transferred to MiniDisc media via SonicStage, chances are these tracks will be locked due to the auto-encryption mechanism embedded in SonicStage. Third, it is worth noting that even though all the tools mentioned above are able to retrieve audio information in their original ATRAC codec (ATRAC 1 or ATRAC 3), the same post-transfer audio file might be wrapped in different wrappers when handled by different applications. For example, an audio track originally recorded in Hi-MD lossless mode is wrapped in .pcm format when transferred by Platinum-MD, while it is wrapped in .wav when transferred by QHiMDTransfer. It is recommended that archivists should use technical metadata survey tools such as MediaInfo and FFprobe to understand the audio tracks better before heading to further conservation and preservation treatments. Last but not least, because developers keep improving and debugging these open-source tools, keeping an eye on latest releases, most recent community discussion and updates of codes and software is highly recommended.

Deck Wiring Approach

In this approach, the author routed back to a more traditional way – extracting audio information from MiniDisc and transferring the signal to the computer sound card directly via analog or digital cables. A professional MiniDisc deck which is equipped with different types of signal outlets is employed for the experiment. This approach allows the greatest level of by-passing software installation and configuration setting up. For example, the method adopted by the Stanford Media Preservation Lab is directly routing the audio signal from the MiniDisc deck to their professional solid-state recorder. In this thesis project, the author still made use of the personal computer, whose purpose is only for receiving audio signal on its sound card instead of for communicating with MiniDisc media via any software interface. To receive audio signal, on the personal computer, certain sound capture software is employed. But results show that, even the basic audio software, such as the QuickTime audio recorder by-default installed in a Mac OS system is already able to capture the audio signal distributed from the MiniDisc deck with proper cable wiring.

In addition to the hardware equipment stated at the beginning of this chapter, below are the devices and cables specifically prepared for this deck wiring approach experiment:

- TASCAM MD-02B MiniDisc professional deck (MDLP)
- Zoom U-44 handy audio/Midi interface
- USB 2.0 cable
- Digital audio coaxial cable with RCA-type connector (S/PDIF port)
- Digital audio optical cable F05/TOSLINK (S/PDIF port)
- Balanced signal XLR cable (left and right channels)
- Audiorecorder - A free tool for the calibration and recording of analog audio signals[123]
- Steinberg WaveLab Elements 10.0 digital audio editor and recording software[124]
- QuickTime player version 10.5

General workflow and results

[123] Audiorecorder, available for download from AMIA Open Source Github page https://github.com/amiaopensource/audiorecorder
[124] WaveLab is a professional sound mastering software, purchasable and downloadable from https://new.steinberg.net/wavelab/

Figure 17 demonstrates the general wiring diagram of the deck wiring approach experiment. Generally speaking, when audio sound is played back from the deck, the audio signal is wired to the personal computer via the interface, which could pipe the signal between the deck and the computer through a set of designated cables. The TASCAM professional MiniDisc deck supports both analog and digital outputs. The author experimented with digital (digital coaxial and digital optical) and analog transmission wires. All of these wiring cables brought decent results.

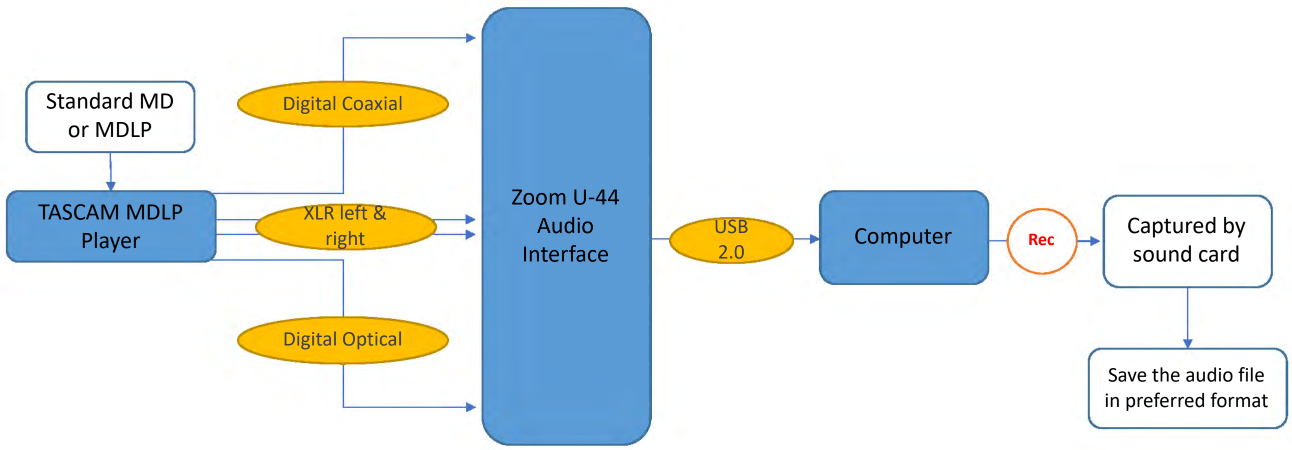

Figure 17. General wiring diagram of the deck wiring approach

For receiving the audio signal distributed from the deck via the interface, the author tried out three types of audio recording software: the free open-source command-line based application Audiorecorder, the paid professional audio software WaveLab Elements and the free software QuickTime player which comes along with Mac OS system. Once the Zoom U-44 interface is connected to the computer, the audio recording software could recognize U-44 as one of the audio-source inputs. Designate U-44 as the audio-source input, hit “record” in the software, and play the MiniDisc in the deck. If oscillating sound wave is seen on the recording software, it means the audio sound is being captured. Upon finishing the recording, hit “stop” and save the file as designated format in the computer. For detailed instructions, see Appendix 5.

All three types of cables effectively piped the audio signal from the deck to the computer, and all three different audio recording software successfully captured the audio information and recorded them as digital audio files saved in the personal computer. That being said, some pros and cons working with different tools are noteworthy.

MiniDisc is a born-digital media format. It is recommended that archivists transfer the audio signal via digital cables, in this case, the digital coaxial or digital optical cables, because by doing this the audio information could be captured at its most authentic and original state. MiniDisc professional decks are usually compatible with S/PDIF digital coaxial and digital optical outputs. S/PDIF stands for Sony/Philips Digital Interface Format. It is a consumer-grade variant of the AES-3 protocol (international standard AES-3: IEC 60958). AES-3 is a standard for the exchange of digital audio signals developed by the Audio Engineering Society and the European Broadcasting Union. AES-3 is capable of carrying two uncompressed channels of uncompressed PCM audio. Under the umbrella of AES-3, S/PDIF digital cables are compatible with a maximum resolution of 20 bits.[125] Since the technical parameter of MiniDisc recording is at 16-bit bit depth, cables under the AES-3 category are adequate enough. It is found that digital coaxial cables carry sounds in a more superior quality and operate more steadily thanks to the wider bandwidth, while optical cables handle long-distant signal transfer better.[126] In the case of MiniDisc, results should show that as long as the transfer distance is not extremely long, digital coaxial cables and optical cables do not generate significantly different results in terms of sound quality and signal transmission speed.

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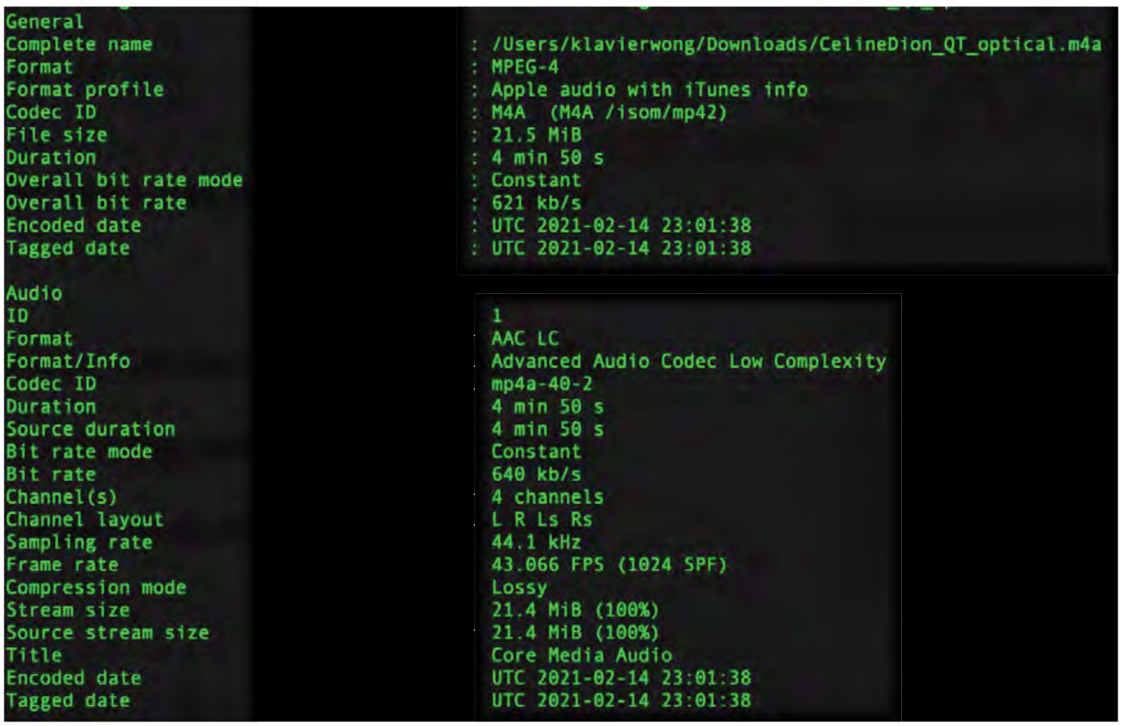
125 "Digital Audio," Cable Bible, AMIA Open Source Github page, https://amiaopensource.github.io/cable-bible/#digital_audio
126 Gary Altunian, "Coaxial vs. Optical Digital Audio Cables," *Lifewire*, January 6, 2020, https://www.lifewire.com/coaxial-vs-optical-digital-cable-3134605

In terms of the application of different audio recording software, QuickTime player offers the most user-friendly option. Once the QuickTime player audio recording interface is activated, the audio signal could be captured simply by pushing the "record" button on the software. But such user-friendly nature obviously leads to its disadvantage – little room to configure signal capturing settings. Therefore, audio information is automatically recorded and saved in a .m4a format with much lower bit rate than those captured by Audiorecorder and WaveLab. Figure 18 shows the MediaInfo-generated technical metadata of a track recorded by QuickTime player.



General	
Complete name	: /Users/klavierwong/Downloads/CelineDion_QT_optical.m4a
Format	: MPEG-4
Format profile	: Apple audio with iTunes info
Codec ID	: M4A (M4A /isom/mp42)
File size	: 21.5 MiB
Duration	: 4 min 50 s
Overall bit rate mode	: Constant
Overall bit rate	: 621 kb/s
Encoded date	: UTC 2021-02-14 23:01:38
Tagged date	: UTC 2021-02-14 23:01:38
Audio	
ID	1
Format	AAC LC
Format/Info	Advanced Audio Codec Low Complexity
Codec ID	mp4a-40-2
Duration	4 min 50 s
Source duration	4 min 50 s
Bit rate mode	Constant
Bit rate	640 kb/s
Channel(s)	4 channels
Channel layout	L R Ls Rs
Sampling rate	44.1 kHz
Frame rate	43.066 FPS (1024 SPF)
Compression mode	Lossy
Stream size	21.4 MiB (100%)
Source stream size	21.4 MiB (100%)
Title	Core Media Audio
Encoded date	UTC 2021-02-14 23:01:38
Tagged date	UTC 2021-02-14 23:01:38

Figure 18. MediaInfo-generated technical metadata of QuickTime player recorded audio track

On the contrary, Audiorecorder and WaveLab provide users different ways to configure technical settings for sound recording. Thus, users are able to command the software to capture the incoming audio at 16 bits and 44.1kHz, which is the same technical parameter of MiniDisc recording. And as opposed to QuickTime player which could only save audio tracks in a lossy .m4a format, Audiorecorder and WaveLab are able to save audio information losslessly.

Audiorecorder by-default saves audio information in broadcast wave format wrapped in .wav. WaveLab provides a list of format options, including lossless PCM wrapped in .wav. Figure 19 and Figure 20 show the MediaInfo-generated technical metadata of an audio track captured by Audiorecorder and WaveLab respectively.

However, it is also important to take into consideration that Audiorecorder is a command-line based tool which expects users to be comfortable working in a command-line environment. WaveLab is a paid software which currently offers 30-day free trial and special discount for educational use.

```
General
Complete name                : /Users/klavierwong/Downloads/CelineDion_audiorecorder_optical.wav
Format                       : Wave
File size                    : 49.4 MiB
Duration                     : 4 min 53 s
Overall bit rate mode        : Constant
Overall bit rate             : 1 411 kb/s
Writing application          : Lavf58.49.100

Audio
Format                       PCM
Format settings              Little / Signed
Codec ID                     1
Duration                     4 min 53 s
Bit rate mode                Constant
Bit rate                     1 411.2 kb/s
Channel(s)                   2 channels
Sampling rate                44.1 kHz
Bit depth                    16 bits
Stream size                  49.4 MiB (100%)
```

Figure 19. MediaInfo-generated technical metadata of Audiorecorder recorded audio track

```
General
Complete name                : /Users/klavierwong/Downloads/CelineDion_WaveLab_optical.wav
Format                       : Wave
File size                    : 50.3 MiB
Duration                     : 4 min 58 s
Overall bit rate mode        : Constant
Overall bit rate             : 1 411 kb/s

Audio
Format                       PCM
Format settings              Little / Signed
Codec ID                     1
Duration                     4 min 58 s
Bit rate mode                Constant
Bit rate                     1 411.2 kb/s
Channel(s)                   2 channels
Sampling rate                44.1 kHz
Bit depth                    16 bits
Stream size                  50.3 MiB (100%)
```

Figure 20. MediaInfo-generated technical metadata of WaveLab recorded audio track

It is also worth noting that, with the deck wiring approach, the protection status of audio tracks stored in MiniDisc media is no longer a problem during the content transfer process, because this approach is more an analog sound capturing procedure than a digital file managing task. Compared to the SonicStage and open-source coding approaches which heavily involve installing different computational applications and require certain degrees of users' digital skills, this deck wiring approach provides a more conventional and straightforward route for archivists who hope to capture audio information in decent quality instead of the digital audio files in their original states. That being said, a major drawback of this approach is the cost of purchasing the devices in need. Due to the obsolescence of MiniDisc, TASCAM remains the only one company continues manufacturing MiniDisc recorder-player in professional deck format, which costs higher than a second-hand MiniDisc Walkman and supply has been shrinking over the years.

Transcoding MiniDisc Tracks

Considering the highly proprietary and unpopular nature of audio files in different versions of ATRAC formats and PCM format, it is recommended that archivists also create audio files in more commonly seen formats for public access besides keeping the original ATRAC-codec and PCM files. In this case, FFmpeg is a good choice. The latest version of FFmpeg – version 4 is versatile enough to encode and decode files in ATRAC codec, including ATRAC1, ATRAC3 and ATRAC3 plus.

For transcoding files in .aea (ATRAC1 codec), .oma, .at3 wrapper (ATRAC3 codec and ATRAC3 plus codec), use FFmpeg to transcode into .mp3 or .wav by typing the below script in the Terminal:

```
ffmpeg -i input_file -f mp3 output_file.mp3

ffmpeg -i input_file -f wav output_file.wav
```

After transcoding, the original codec will be transcoded into MPEG version 1 for tracks wrapped in .mp3, and for tracks wrapped in .wav, the codec will be PCM.

However, so far FFmpeg is not able to encode audio tracks recorded in Hi-MD lossless PCM mode. For transcoding audio tracks in this nature, the open-source free-to-download software "Audacity"[127] is a good choice.

- Follow instructions to download Audacity to your computer
- Import the .pcm file as "Raw Data"
- Configure the importing setting to PCM 16 bit, 44100HZ – the technical parameter of the original PCM file
- Load the PCM file
- Export the PCM file into a desired format (e.g. .wav, .mp3)

[127] Download from https://www.audacityteam.org/download/

Chapter Five: Conclusion

Once upon a time, hoisting the banner of digital media forerunner, MiniDisc defeated its strongest rival - the Philips DCC - and became an acclaimed revolutionary media format adored by general music lovers and media professionals. But as a media format which could have done no wrong[128], misfortune awaited MiniDisc, and it was to suffer from the irresistible tides of more economical and less software and hardware dependent digital media formats. That being said, this plastic cassette, with its secured sheen and glittering cookie-sized optical disc, capable of accommodating as many tracks as three CDs, still fascinates many music lovers around the world. Outside of the music world, due to the once popularity of this media format, in many archival organizations, MiniDisc is found to be one of the media storage mediums that have recorded valuable historical audio information. But being an obsolete media format with high software and hardware dependencies, MiniDisc leads to many archival challenges to the AV archivist community.

Handling MiniDisc, like the process of digital preservation itself, is by no means an ending journey, at least at the point when this thesis project is drawing to a concluding remark. This thesis project standss more as a work of reference and documentation of the latest findings about MiniDisc, rather than providing final solutions to puzzles derived from this media format. To retrieve the valuable audio information once securely stored in the MiniDisc, while some archivists choose to maintain a legacy SonicStage software running in the lab, some technicians opt for developing open-source tools to communicate with MiniDisc devices in a more flexible way. Tremendous efforts on reverse-engineering this highly proprietary media format and

[128] Nilay Patel, "Status Symbols: MiniDisc"

keeping this media alive have been approached by people from multiple directions. And thanks to these efforts, the author is able to come up with a handful of practical open-source oriented workflows without engaging with a series of constraints brought by MiniDisc's software and hardware dependencies. But even until now, to many AV archivists, media technicians, computer engineers, as well as a massive population of MiniDisc users and hobbyists, understanding more about this media format and its derivative applications still requires a long journey of research and experiments.

To conclude this thesis project, some tips for handling MiniDisc in archival organization settings and possible further research directions are provided below. These archival-oriented tips, along with the detailed workflow documentation presented in Chapter Four and in Appendixes, intend to serve the large archival community as the daily work of reference and an advancement of understanding optical media.

First of all, considering that MiniDisc has heavy software and hardware dependencies, it is important to have a clear budget plan and technical needs in hand before embarking a MiniDisc content migration project. Essential questions to ask include: What is the budget for purchasing a MiniDisc player? Are the archivists comfortable working with command-lines and legacy computer operating system? If not, do they have sufficient technical support? If the deck wiring approach is to be chosen, do we have technical support?

Secondly, speaking of appliance purchase, it is strongly recommended that archival organizations purchase Hi-MD players in order to playback MiniDisc media recorded in different modes. Hi-MD is the latest and last MiniDisc system developed by Sony, embracing the most versatile backward compatibility – playing back discs formatted in standard, long-play and Hi-MD modes and audio tracks encoded in different versions of ATRAC. So far, according to the author's interviews with media professionals, Sony's MZ-RH1/M200 is the most championed model. It is available in second-hand market. If with budget constraint, a MDLP model is also accepted, whose price would be much lower than a Hi-MD model.

Thirdly, in terms of choosing between different approaches to retrieve and archive digital contents stored in MiniDisc, it depends on a few factors: the availability of software and hardware resourses, the digital comfort level of the responsible archivists, and the purposes and goals of handling the MiniDisc collections (bit-by-bit preservation of digital files or preservation of the contents). As mentioned in the previous chapter, the open-source coding approach is the one that costs least - only a MiniDisc player and a computer are required to fulfil the hardware dependency of MiniDisc. Other than these, all needed computational tools are free to use and are compatible with the latest computational environment. The SonicStage-reliant approach is also a money-saving one. While this approach requires users to fulfill both the software and hardware dependencies of MiniDisc, the software needed is available on the Internet free of charge. These two approaches demand certain levels of tech-savviness of the archivists, but through these methods, the digital files stored in MiniDiscs could be retrieved in their original technical states – the ATRAC codec files or the PCM lossless format. Having digital files as closely authentic to their original states as possible – the bit-by-bit migration from a medium to another - is recommended for long-term digital preservation. And both the open-source coding approach and the SonicStage-reliant approach can meet this need. On the other hand, if the archivist in-charge is more comfortable with a traditional method of audio content migration and the purpose of retrieving the audio files from MiniDiscs is more content-oriented than digital file-focused, the deck wiring approach could meet the needs. According to the author's experiments, audio information transferred from the MiniDisc deck to the personal computer via both analog and digital cables generate satisfying results – clearly defined human voices and wide spectrum of environment sounds are captured. Therefore, there is no correct answer to the choice of MiniDisc content migration approach, and the real situation and the needs of an organization are the most important factors when making decisions.

Fourth, some miscellaneous issues are also worth attention. Although in daily archival works, it is important to take note of the physical condition and appearance of a media object, in the case of MiniDisc, the appearance of a disc does not tell the whole story. A disc without "Hi-MD" etched on the plastic case does not mean that it could not hold audio information recorded in Hi-MD modes. As illustrated in Figure 11 (Chapter Three), a standard MiniDisc could record tracks in Hi-MD modes if the disc is formatted correctly in Hi-MD recorder. Hence, taking note of the physical appearance of the disc and the real technical metadata of the stored contents (when the disc is read by the software) are equally important. Similar to many cassette-based media, MiniDisc has its write-protection tab. During preservation treatments, having the tab on is a recommended action to protect the original data from being accidentally erased. Generally speaking, since the cookie-sized optical disc is permanently secured in a plastic cassette, cleaning is seldom needed during preservation treatments.

Last but not least, for further research on MiniDisc, archivists and media professionals may want to collaborate with computer engineers, software developers and audio engineers to advance understanding on this media format and its affiliated proprietary software and hardware. For example, open-source tools for effectively handling Hi-MD discs and communicating with Hi-MD players are still under development and testing. Another research direction could be MiniDisc disc imaging technology. So far, a dedicated software or computer application tool for

MiniDisc forensic analysis or imaging is not yet available.[129] But with knowledge about the track layout of MiniDisc, which is available in Sony's technical reports to help people's understanding of the data arrangement structure and the metadata location in the disc, development of tools for MiniDisc digital forensic are possible and foreseeable.

[129] Dedicated tools for analyzing and imaging CD, CD-ROM and DVD are widely available among the AV archivists community, such as IsoBuster, Exact Audio Copy, dBpoweramp, cdparanoia, etc.

Appendix 1.

Archival organizations	Collections holding MiniDisc materials
Duke University - David M. Rubenstein Rare Book and Manuscript Library	Vincent Cianni photographs 1983-2012
Duke University - David M. Rubenstein Rare Book and Manuscript Library	Radio TV Reports Infomercial collection 1990-1996
UCLA - Library Special Collections, Performing Arts	Martin Perlich interviews 1965-2008
UCLA - Charles E. Young Research Library	Lewis MacAdams papers 1944-2014
Library of Congress – Research and Reference Services	Voices of Civil Rights Project collection 2003-2004 2003-2006 2003-2004
University of Washington	UW Ethnomusicology Archives audio recordings: Deva Wells recordings (Music of Cienfuegos) 2007
Stanford University	Gene Golub papers 1950-2007
Stanford University	Center for Advanced Study in the Behavioral Sciences records 1952-2010
Stanford University – Archive of Recorded Sound	Croatian American Cultural Center Collection 2000-2016
Stanford University - Archive of Recorded Sound	Reese Erlich Jazz Programs and Interviews Collection 1994-2017
Stanford University - Archive of Recorded Sound	Riverwalk Jazz Collection 1987-2012
Stanford University - Hoover Institution Library and Archives	Said Hyder Akbar sound recordings 2002-2003
Stanford University - Hoover Institution Library and Archives	Radio Free Europe/Radio Liberty broadcast records 1951-2005
Stanford University - Hoover Institution Library and Archives	Commonwealth Club of California records 1903-2012
Harvard University – Schlesinger Library	Papers of Jean V. Hardisty
Cornell University - Division of Rare and Manuscript Collections	Robert Moog papers, circa 1965-2005.
Smithsonian – Anacostia Community Museum	Exhibition records 2003-2004
Smithsonian – Anacostia Community Museum	Exhibition records 2005
Smithsonian – Anacostia Community Museum	Audiovisual Records 2004
Smithsonian Institution – National Museum of American History	Nathaniel Mathis Collection of Barbering and Beauty Culture 1946-2004

Smithsonian Institution - National Museum of American History	Ella Fitzgerald Papers circa 1935-1996
Yale University - Beinecke Rare Book and Manuscript Library	Jean-François Bory Papers 1957 2015
Yale University - Beinecke Rare Book and Manuscript Library	Henri Chopin papers 1948 2009
New York University – Fales Library	Betty Fussell Papers MSS 160
The New York Public Library	Ping Chong Archive. Audio materials
East Georgia State College	Jimmy Carter historical and publicity materials, East Georgia College visit, February 2003
University of North Carolina, Charlotte - J. Murrey Atkins Library	Ronald R. Caldwell oral history interview, 2005 May 31
University of Oregon	Harry S. Stamper, Jr. papers 1965-2013
Emory University - Archives, and Rare Book Library	Rita Ann Higgins papers, 1968-2017
Monmouth County Library (N.J.)	Remembering the 20th century: an oral history of Monmouth County, 1999-2000
New Jersey Historical Society	Manuscript Group 1600, Guide to the Changed Lives: New Jersey Remembers September 11, 2001
KBOO Community Radio	News and public affairs audio collection, 1947-2013
Center for the Study of Upper Midwestern Cultures	Summer Field School 2000 Collection, 2000 June-July
University of Michigan – Bentley Historical Library	Dan Sicko Papers
Texas Tech University - Southwest Collection/Special Collections Library	William E. Bass oral history interview
Texas Tech University - Southwest Collection/Special Collections Library	Doris Lee Fletcher oral history interview
Texas Tech University - Southwest Collection/Special Collections Library	Jim Gatteys oral history interview
Texas Tech University - Southwest Collection/Special Collections Library	Raymond Flores oral history interview
Texas Tech University - Southwest Collection/Special Collections Library	Ronda Langston oral history interview
Texas Tech University - Southwest Collection/Special Collections Library	Dean Weese oral history interview

Texas Tech University - Southwest Collection/Special Collections Library	Bob Gene Schneider oral history interview
Texas Tech University - Southwest Collection/Special Collections Library	Roger Robles oral history interview
University of Texas at Austin - Harry Ransom Center	McSweeney's Records circa 1930s-2013 (bulk 2000-2012)
University of Texas at Austin - Benson Latin American Collection	Center for Mexican American Studies Records 1959-2011,
Rutgers University Libraries - Institute of Jazz Studies	Andrew Hill papers, music and audiovisual recordings, 1956-2011
University of Tennessee at Knoxville	University of Tennessee Theatre Collection
Indiana University Archives of African American Music and Culture	James Spooner Collection approximately 2000-2007
Indiana University - Archives of African American Music and Culture	Logan H. Westbrooks Collection 1936-2016
University of Montana - Maureen and Mike Mansfield Library	YWCA of Missoula records 1911-2014
Wisconsin Historical Society Library and Archives	Wisconsin Society for Jewish Learning Records, 1954-2012
Whitman College	Confluence Project records 1996-2017
University of Montana - Maureen and Mike Mansfield Library	University of Montana publications (UPUBs) collection 1895-2019
Northern Arizona University - Cline Library	Martin Litton Collection, 1937-2004
East Carolina University - Joyner Library	Records of the College of Fine Arts and Communication: Records of the School of Music - Collection Guides

Appendix 2.

The workflow of handling MiniDisc media at the Stanford Media Preservation Lab:

1. The physical MiniDisc media are photographed, catalogued as digital objects in the DAMS (digital assets management system), and assigned unique identifiers.
2. A MiniDisc media is loaded in the MZ-M200 player, which is connected with the computer via a USB cable. SonicStage will then be launched to read files from the player.
3. SonicStage is configured to "standard transfer mode" and .wav file format is selected as post-transfer export format. A local directory is also selected for storing exported files.
4. Audio files are transferred from the MiniDisc player to the local computer. When a MiniDisc is ripped, SonicStage will create .oma files and .wav files, which are both saved for preservation purposes.
5. If the MiniDisc tracks have human-entered track names (something other than auto-assigned numbers), copy these names and titles to a plain text file. This file will live with the preservation masters in the preservation folder.
6. If multiple tracks of the same program (e.g. the same interview) are stored in one MiniDisc, these tracks will be merged into one track for creating derivatives. Access files in .m4a format will be created.

Appendix 3.

Workflow of handling MiniDisc collection at The Manchester Central Library, the United Kingdom:

1. Launch SonicStage on Windows 10, connect the MiniDisc player with the computer, and read the audio files saved in the MiniDisc media.
2. Create catalogue for each interview record (if existing catalogue record does not exist). For interviews with existing cataloguing record, cross check the existing records with the audio tracks saved in the discs and ensure the disc labels match the existing records.
3. Transfer audio files from the MiniDisc player to the local directory. The audio files are saved as .wav format (a SonicStage pre-set configuration).
4. Once the audio files land in the local directory, rename the files according to the cataloguing rules.
5. Listen to each audio track to ensure the contents are transferred correctly. If a file is corrupted, the archivists need to figure out whether it is an error in the transfer process or an issue with the original disc. The spectrogram function in Wavelab Elements 9.5 is utilized to check for digital dropouts. If an error comes from the transfer process, re-transfer the disc is necessary.
6. Conduct sound quality check (e.g. fuzzy or whines).
7. Log the tracking sheet which documents which discs are transferred, catalogued, checked and ingested.
8. A copy of the checked-over audio file is also prepared for ingesting to The British Library.

9. If a MiniDisc media contains multiple tracks which belong to the same interview, take notes of the lengths of each track and ensure the tracks are in correct order after transfer to the local directory. Each individual track at their original state is saved as preservation master and a joint-version is also created (a software called Shuangs Audio Joiner is used).
10. Under each oral history project, two folders are created – “Raw” and “Ingest”. The “Raw” folder stores audio files directly transferred from the MiniDisc media at their original states. The “Ingest” folder contains checked-over audio files and joint-audio files which are to be ingested to the British Library archive system.

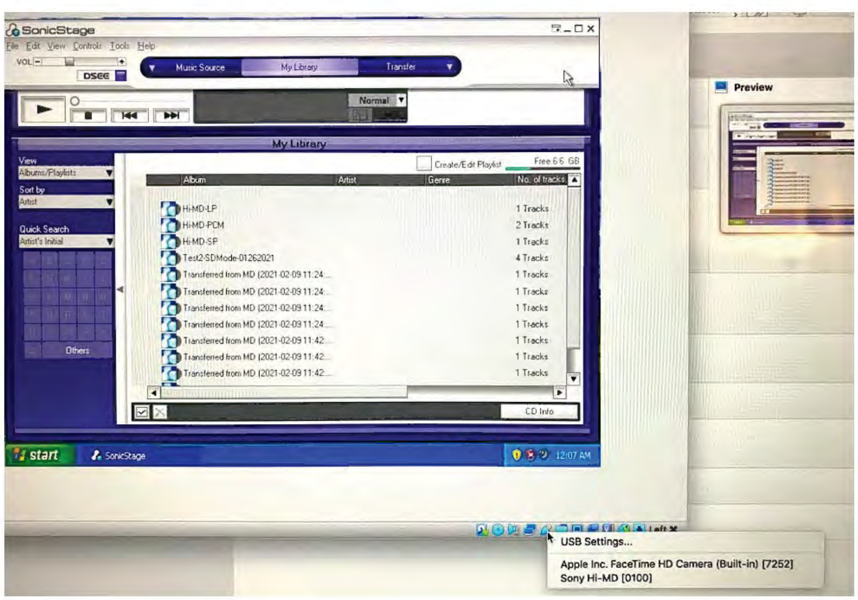
Appendix 4.

Below is the step-by-step SonicStage set-up instruction for archivists' reference.

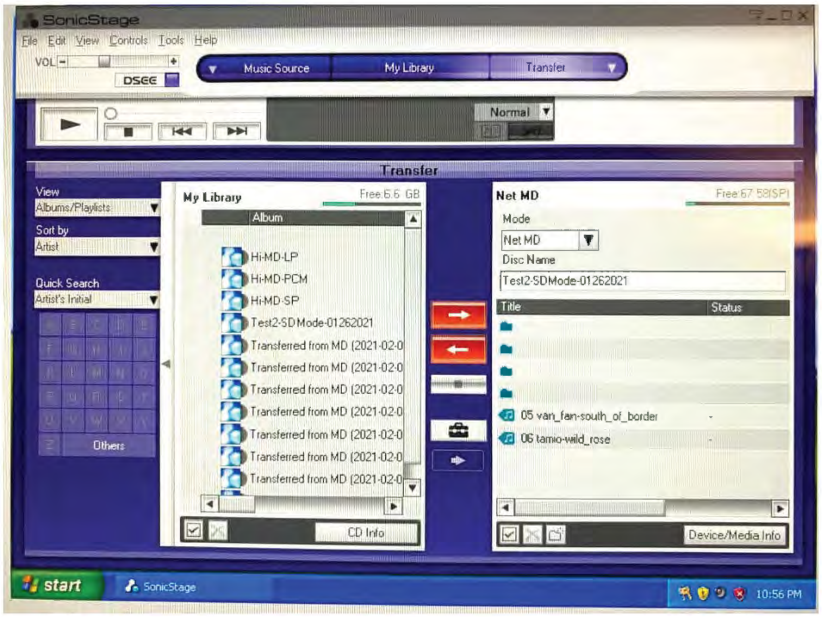
1. Install and run the emulator (in this case, VirtualBox is in use).

2. Install and run SonicStage 4.3 Ultimate in the Windows XP environment.

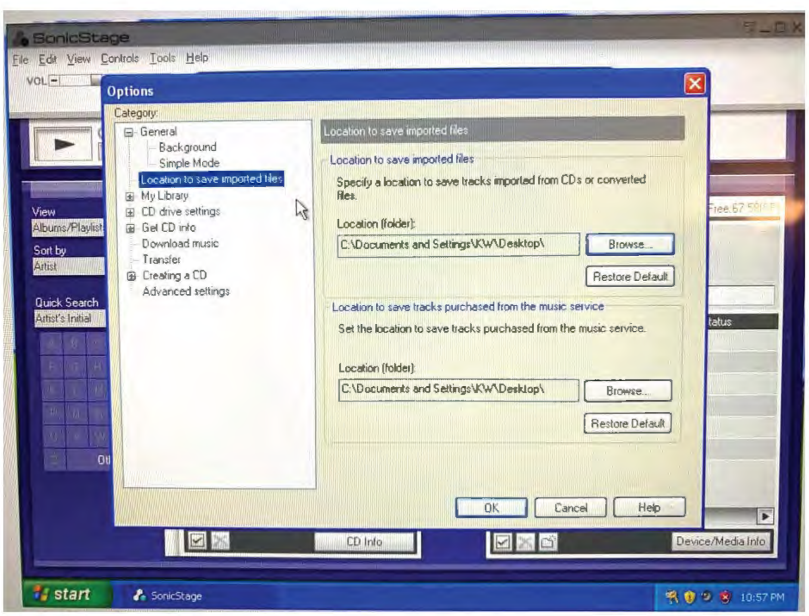
3. Connect the MD player to your computer using the supplied USB cable (should be USB 2.0). SonicStage should automatically recognize the device. If not, manually connect the device to the emulator as shown below.



4. Insert a Minidisc into the MD player. Navigate to the transfer tab. You should see the list of tracks stored in the MiniDisc media.

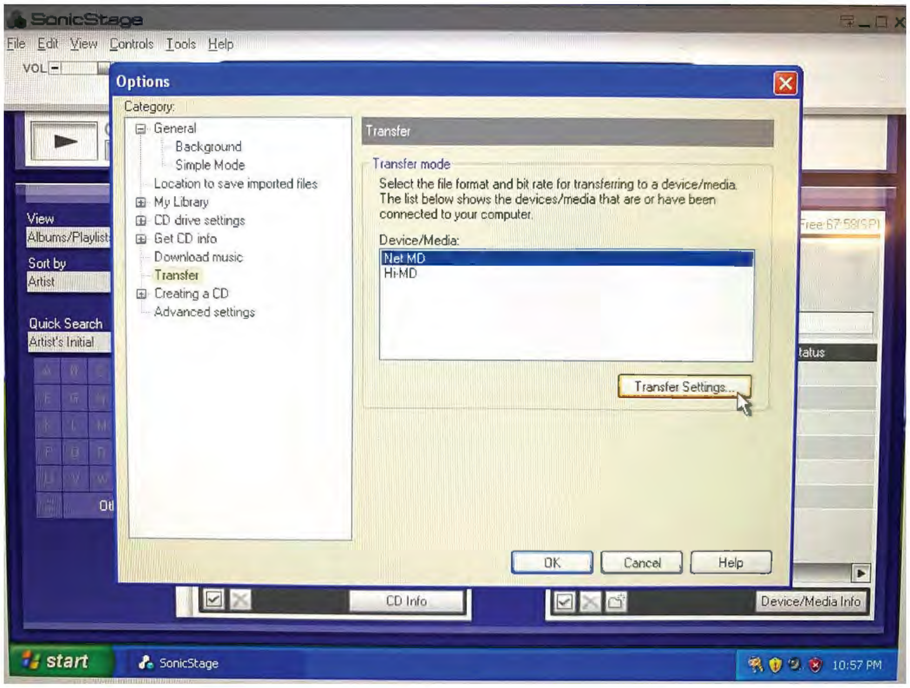


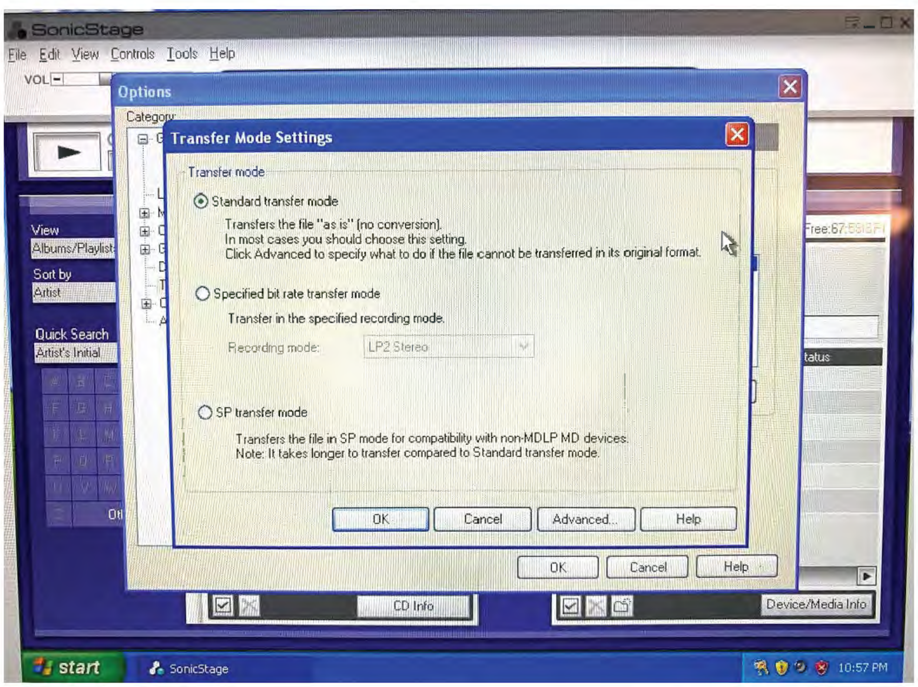
5. Assign the destination directory for the tracks which will be transferred from MD player to the computer. Navigate to Tools → Location to save imported files



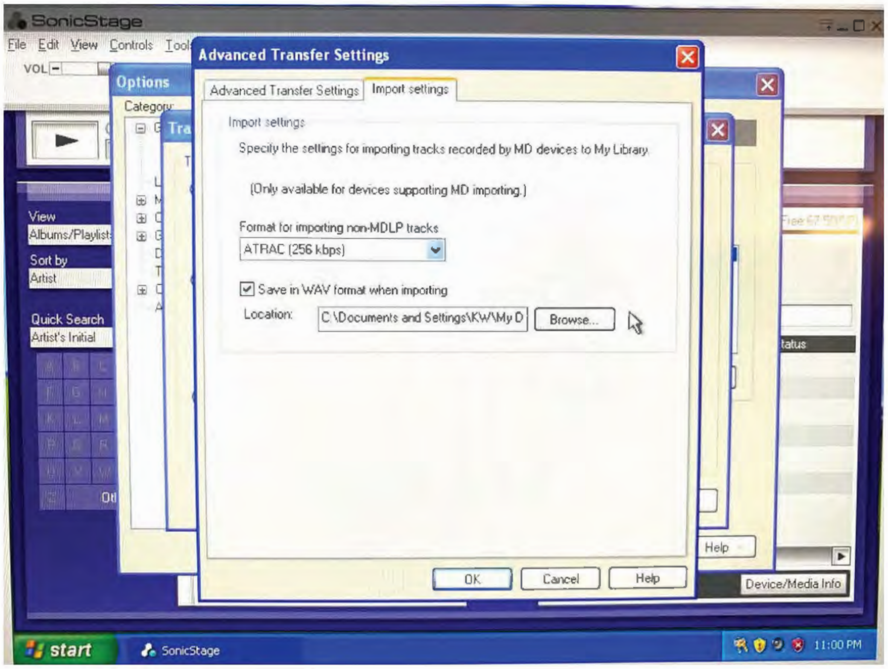
6. If you want to transfer the audio tracks in their original states (keeping the ATRAC codec), navigate to Tools → Options → Transfer → NetMD (or select Hi-MD if you

insert a Hi-MD mode disc) → Transfer Settings → Standard transfer mode (Transfer the file "as is")





7. If you also hope to save another set of audio files in .wav format as mezzanine or access copies, under Transfer Mode Settings, click Advanced → Import settings → Check Save in WAV format when importing → Assign a receiving destination directory



8. After configuring the settings according to your needs, go back to the main SonicStage interface. Select the audio tracks you want to transfer. Click the left-directed arrow. When transfer process is completed, the tracks will be saved in the directory you chose.

9. After transfer, tracks originated recorded in standard modes are look like this

001-SP.oma	Feb 9, 2021 at 11:42	1.1 MB	Feb 9, 2021 at 16:06
002-LP2.oma	Feb 9, 2021 at 11:42	571 KB	Feb 9, 2021 at 16:06
003-LP4.oma	Feb 9, 2021 at 11:42	267 KB	Feb 9, 2021 at 16:06
004-tamio-the_ate_of_the_times.oma	Feb 9, 2021 at 11:42	4.8 MB	Feb 9, 2021 at 16:06
005-van_fan-south_of_border.oma	Feb 9, 2021 at 11:42	3.6 MB	Feb 9, 2021 at 16:06
006-tamio-wild_rose.oma	Feb 9, 2021 at 11:42	2.6 MB	Feb 9, 2021 at 16:06

10. After transfer, tracks originated recorded in Hi-MD modes are look like this

Hi-MD-SP.oma	Feb 9, 2021 at 16:02	1 MB	Feb 9, 2021 at 16:07
Hi-MD-PCM.oma	Feb 9, 2021 at 16:02	6.3 MB	Feb 9, 2021 at 16:07
Hi-MD-LP.oma	Feb 9, 2021 at 16:02	272 KB	Feb 9, 2021 at 16:07

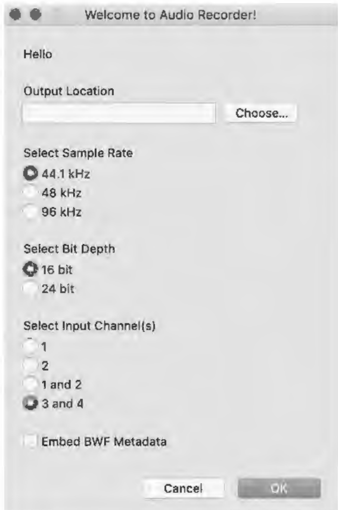
Appendix 5.

Below is the instruction for capturing and recording MiniDisc audio information through wiring TASCAM MD-02B MiniDisc deck with the author's Mac OS computer. The signal is wired through Zoom U-44 interface and is piped through digital cables. Wiring with both a digital coaxial cable and a digital optical cable follows the same procedure. For archival purpose, it is recommended that audio information is captured as true as possible to its original technical state. Therefore, the below instruction focuses on working with Audiorecorder and WaveLab which enables audio recording in lossless mode.

1. Install the audio recording software:
    a. For Audiorecorder: refer to the step-by-step instruction here (https://github.com/amiaopensource/audiorecorder). If the GUI of Audiorecorder does not pop up, try `brew install pashua` in Terminal, then try again.
    b. For WaveLab Elements: after downloading the software via (https://new.steinberg.net/wavelab/), follow every step instructed in every pop-up window to set up the license, the helper and the software.
2. Connect the deck with U-44 interface with a digital cable. Connect U-44 with the computer via a USB 2.0 port.
3. Switch on the deck and U-44.
4. Important note: Zoom U-44 sets aside channel 1 and 2 for analog signal transfer (e.g. XLR cable transfer). Channels 3 and 4 are for digital signal transfer. If working with U-44, it is important to indicate the correct audio source input in the recording software.

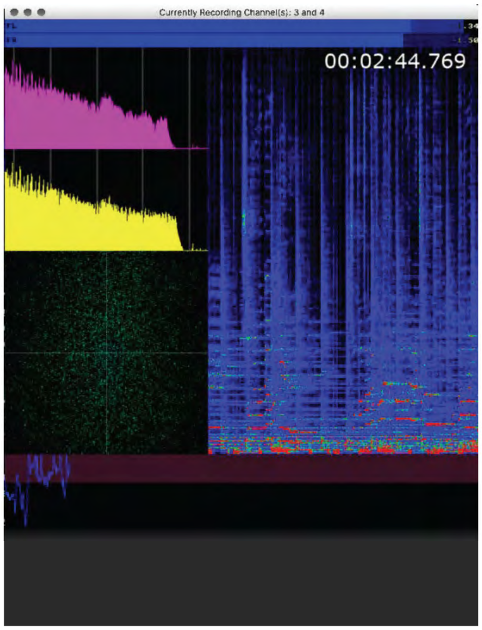
5. Important note: On U-44, correctly select the S/PDIF input source to either optical or coaxial.

6. For recording in **Audiorecorder**:
    a. In Terminal, run command `audiorecorder -e` to set up the sampling frequency and destination directory. Importantly, "Select Input Channel(s)" 3 and 4.



b. After setting up the sampling frequency according to your needs, in Terminal, type `audiorecorder -p` to open a preview interface. From here, you can hit "Play" at your MD deck and check if the audio signal is successfully wiring into the audio recording software. Since it is a preview interface, no actual file is captured at this moment. Once everything is satisfying, escape the preview interface.

c. For actually recording the audio, in Terminal, type `audiorecorder`. Audio signal recording commences. Then hit "Play" at the MD deck. A graphic interface will show at this moment to demonstrate the incoming signal in different forms.

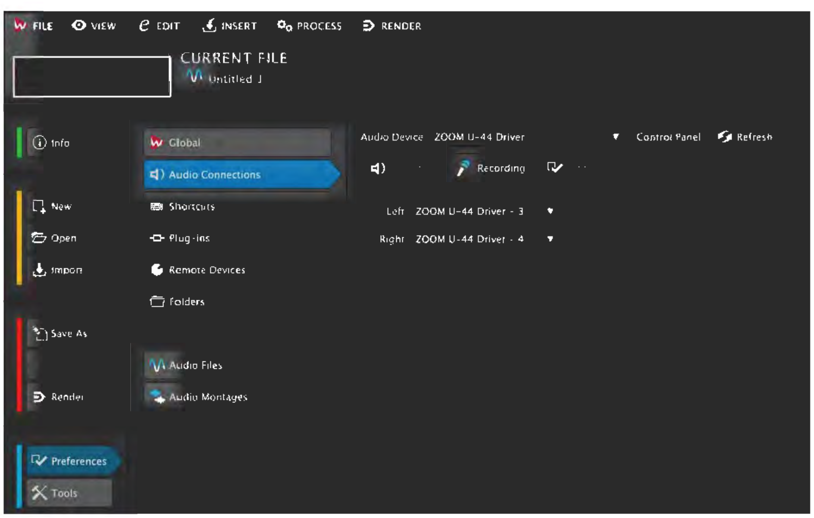


d. Once finish recording, escape the graphic interface. Then in the Terminal, Audiorecorder will ask you to input a file name for the audio track just captured.

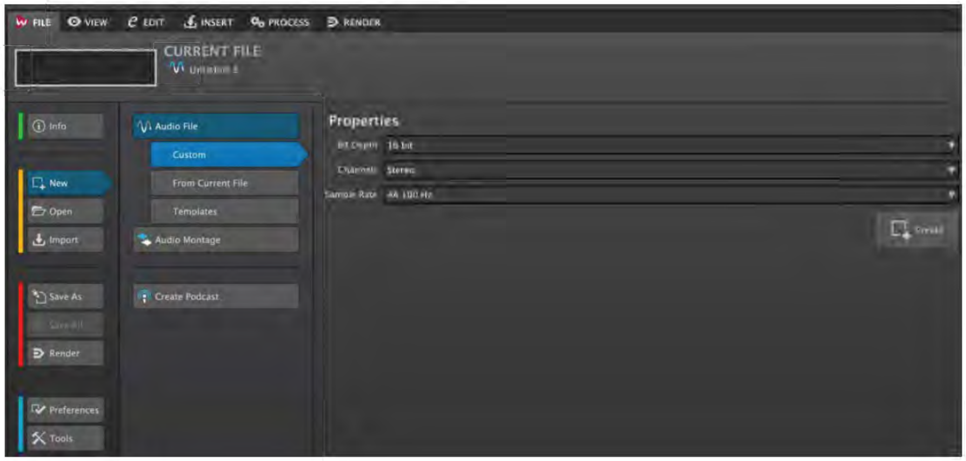
7. For recording in WaveLab Element 10:

   a. Create a new audio file

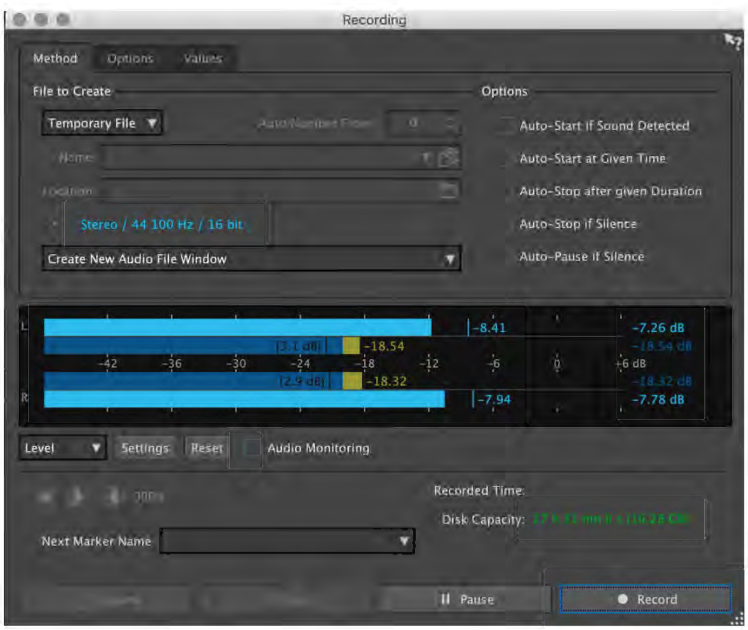
   b. In the “File” panel, in Preferences → Audio Connections, make sure select “Zoom U-44” as the audio device and set up channel 3 and 4 as incoming channels.



c. In New → Custom, set up the desired bit depth and sample rate.

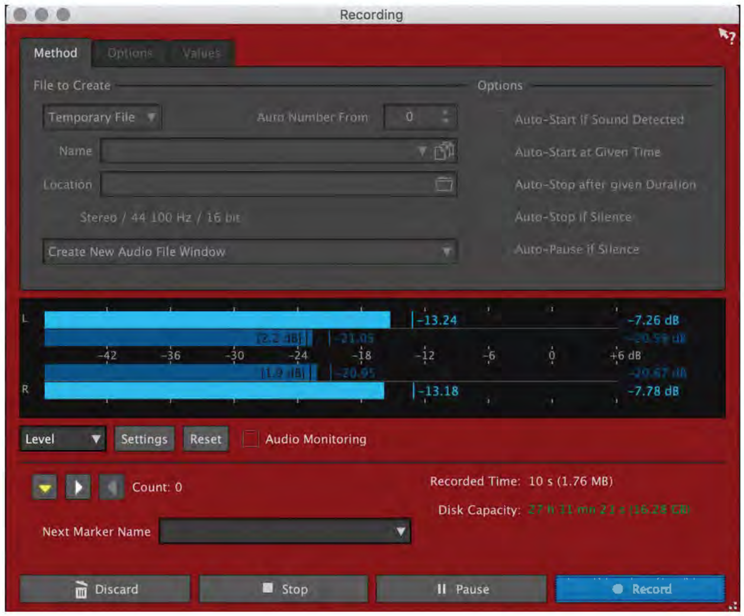


d. Back to the "View" panel, hit "record". A new recording window will pop up. Hit "Play" at the MD deck. At this point, oscillating sound wave should show up, implying that audio signal is detected.



e. After ensuring audio signal could be detected, hit "Stop" at the MD deck.

f. Now, for actual recording, press the "record" button at this recording interface, then hit "Play" at the MD deck. When recording is in progress, the recording window will turn red.



g. When recording is completed, press "Stop" and go back to the "View" panel.

h. Save the file in desired file format.

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