

Digital Audio Tapes: Their Preservation and Conversion

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Overview

Digital Audio Tapes (DATs) are 4mm (or 3.81mm) magnetic tape cassettes that store audio information in a digital manner. DATs are visually similar to compact audio cassettes, though approximately half the size, use thinner tapes, and can only be recorded on one side. Developed by Sony in 1987, DATs were quite popular in recording studios and were one of the first digital recording systems to become employed in archives in the late 1980s and 1990s due to their lossless encoding. Commercial use of DATs, on the other hand, never achieved the same success as the machines were expensive and commercial recordings were not available on DAT.

Depending on the tape and machine used, DATs allow four different sampling modes: 32 kHz at 12 bits quantization, and 32 kHz, 44.1 kHz, and 48 kHz at 16 bits.¹ All support two-channel stereo recording. Some of the later DATs (before being discontinued) could extend the bit-depth to 24 and up to 98 kHz, however, these tapes were likely rarely playable on other models.² DATs can run between 15 and 180 minutes in length, one again depending on the tape and quality of the sampling. Unlike some other digital media, DATs do not use lossy data compression, which is important in the lossless transferring of a digital source to a DAT. Sony ultimately discontinued the production of DAT machines in 2005.³

Composition

A digital magnetic tape is composed of two primary layers: the base film and magnetic layer. Some tapes may also have a matt back coating of pigments and a polymer binder to improve winding and reduce static charge, improving durability and playback.⁴ The base layer of a DAT is most likely polyester (composed of a polymer of ethylene glycol and terephthalic or naphthalene dicarboxylic acid),⁵ as this material was used in the composition of magnetic tapes after 1950 (with the Image Permanence Institute identifying the introduction date as 1963).⁶ The magnetic layers contain magnetic pigments made from pure iron particles within a polyurethane binder. Analog magnetic tapes usually contain iron oxide elementary magnets; however, these are too large to deal with the high-density data of digital audio and video, thus the use of pure iron particles.⁷ Also, the magnetic coatings often contain lubricants to minimize friction between the tape and the recording/playing heads.⁸ Each of the physical elements of a DAT lends itself to preservation and conversion issues, which will be discussed in a later section.

¹ "Digital Audio Tape," Wikipedia. http://en.wikipedia.org/wiki/Digital_Audio_Tape

² "Digital Audio Tapes," <http://audiotools.com/dat.html>

³ "Digital Audio Tape," Wikipedia

⁴ Dietrich Schuller, *Audio and video carriers: Recording principles, storage and handling, maintenance of equipment, format and equipment obsolescence*, Amsterdam: European Commission on Preservation and Access, 2007, 6. http://www.tape-online.net/docs/audio_and_video_carriers.pdf. Peter Adelstein, *IPI Media Storage Quick Reference Guide*, Image Permanence Institute, 7. http://www.imagepermanenceinstitute.org/shtml_sub/MSQR.pdf.

⁵ Adelstein, 9.

⁶ Adelstein, 8.

⁷ Schuller, 6.

⁸ Schuller, 7.

Recording Process

Digital audio and video tapes are able to store high data densities through the use of these thin tapes, magnetic pigments, and a slightly different recording process than their analog counterparts. Digital audio recordings measure (sample) the level of a sound wave at a regular interval and then record this information as a discrete value using a predefined number of binary bits.⁹ This bitstream is the raw audio data that is used to reconstruct the original waveform when played back.¹⁰ “Audio sampling is based on the Nyquist-Shannon sampling theorem, which concludes that for accurate signal reconstruction the sampling frequency should be at least twice the bandwidth of the source signal.”¹¹ The sample rate (frequency) is the “rate at which the samples are captured or played back, measured in Hertz (Hz).”¹² This is equivalent to the horizontal precision of the digital waveform.¹³ Higher sampling rates also allow for accurate recordings of higher frequencies. It is thought that the “maximum essential frequency audible to the human ear is approximately 20KHz....therefore in audio systems the minimum sampling rate needs to be approximately 40KHz.”¹⁴ If the sampling frequency is not at least twice the bandwidth of the source signal then aliasing (distortion resulting when the signal reconstructed from the samples does not match the original signal) can occur.¹⁵

The sample format (sample size or sample-width) is “the number of digits in the digital representation of each sample.”¹⁶ Whereas the sample rate is the horizontal precision, the sample size is the vertical precision of the digital waveform. Higher sample sizes provide for more dynamic range, described as louder “louds” and softer “softs.”¹⁷ With lower bit-depth comes the problem of quantization, wherein gaps between the samples are rounded up to the nearest value, producing noise. The more accurate the sample reading compared with the original signal, the lesser the chances of quantization.¹⁸

A DAT recorder utilizes elements of both videotape and CD technologies. To record on digital magnetic tapes, the tape moves across an electromagnet recording head, which produces a magnetic field that varies according to the signal it receives from the recording device.¹⁹ As digital tapes store high density data, a higher band-width and recording speed than analog magnetic tapes is required. In order to accommodate this, digital magnetic tapes are recorded using a rotating head (analog uses a stationary head), which leads to a helical scan, “in which the rotating head writes tracks at an angle to the direction of tape travel.”²⁰ Thus the head is able to

⁹ “Uncompressed Audio File Formats,” JISC Digital Media, <http://www.jiscdigitalmedia.ac.uk/audio/advice/uncompressed-audio-file-formats>.

¹⁰ Ibid.

¹¹ “An Introduction to Media, <http://www.jiscdigitalmedia.ac.uk/audio/advice/an-introduction-to-digital-audio/>

¹² Audacity v.1.2.4 Online Help, <http://audacity.sourceforge.net/onlinehelp-1.2/reference.html>.

¹³ Audacity v.1.2. Manual, <http://audacity.sourceforge.net/manual-1.2/>

¹⁴ “An Introduction to Digital Audio,” JISC

¹⁵ “Aliasing,” <http://en.wikipedia.org/wiki/Aliasing> Digital Audio,” JISC Digital

¹⁶ Audacity manual.

¹⁷ Ibid.

¹⁸ “An Introduction to Digital Audio,” JISC

¹⁹ Schuller, 5.

²⁰ Jay Kadis, “Digital Audio Recorders,” 2006, https://ccrma.stanford.edu/courses/192b/192b_Lecture_4_06.pdf, 2.

move at a higher speed, while the tape moves at a slower speed, in order to capture the higher density data without requiring absurd tape lengths.²¹ In terms of mechanics, “the rotating drum contains two separate heads 180 degrees apart” with each head maintaining “contact with the tape for 90 degrees, with the tape wrapped around the head the same 90 degrees.”²² Though this results in a discontinuous signal coming off the heads, as the signal is already a discrete signal, this is not an issue.²³ In order to synchronize tape movement and the rotation of the heads, “on either side of the PCM data, a special ATF (automatic [or area-divided] track following...) signal burst is recorded,” which is then used by each head to “servo the capstan rotation and thereby align the tracks and heads.”²⁴ However, this process means that DATs cannot be physically edited by cutting and splicing like analog or open-reel digital tapes.²⁵

Also included in the signal data are sub codes, which indicate the start and end of tracks in order to allow for indexing and can count absolute time from the beginning of the tape.²⁶ Along with analog inputs and outputs, DATs have digital input and output that allows copying directly onto another DAT; a digital-to-digital copy, and therefore (supposedly) lossless.²⁷ Finally, the signals can then be retrieved by “running a tape across a replay head, which picks up the magnetic information and converts it back into an electric signal.”²⁸

As will be discussed in later sections, the alignment of the DAT machine plays an important role in both the recording and playing of the tapes. For best recording (and by extension, playback), blank DATs should be fast-forwarded completely and then rewound just prior to recording, in order to align the tension of the tape with that of the machine.²⁹ Also, there should be enough room left blank before and after the recording in order to prevent the loss of information caused by the stress of loading and unloading.³⁰

Physical Preservation Issues

There are physical preservation issues that accompany each element of a digital magnetic tape. In general, as with many other audio/visual formats, there is the risk of mold if stored in humid or warm conditions, which can eat away at the magnetic layers.³¹ More specifically for magnetic tapes, while the base layer of polyester is considered “mechanically stable and chemically robust,” with rising temperatures comes thermal expansion, increasing tension within the tape pack.³² Rising temperatures can also cause print-through in magnetic tapes, where the magnetized tape of one section causes the magnetization of tape wrapped around it. This cause

²¹ Schuller, 6.

²² Kadis, 3.

²³ Ibid.

²⁴ Ibid.

²⁵ “Digital Audio Tape,” Wikipedia.

²⁶ Ibid.

²⁷ “FAQ,” Dat-Heads, <http://www.solorb.com/dat-heads/FAQ>

²⁸ Schuller, 5.

²⁹ George Blood phone interview.

³⁰ Schuller 11

³¹ Schuller, 10

³² Schuller, 10.

pre-echo and post-echo in playback, though DATs are more resistant to print-through than reel-to-reel given their greater retention of their magnetic signal.³³

The pure iron particles in the magnetic layers are subject to oxidation and the pigment binders themselves, in some cases, can break down completely, resulting in complete loss of the information carried in the magnetic layer.³⁴ The use of polyester urethane binders also can cause hydrolysis, a chemical reaction between water in the air and the polymers in the polyurethane, changing the chemical and physical properties of the original polymer.³⁵ This often produces a by-product, which acts as an auto-catalyst, which enhances the destructive process.³⁶ This causes the tapes to become sticky, squeal when played, and shed magnetic powder on audio heads, which clogs them and leads to significant loss of high frequencies. The lubricants can also cause clogging, along with dust and other foreign matter.³⁷

Digital magnetic tapes are more resistant to magnetic influences than analog magnetic tapes, though caution should be taken in regards to exposing magnetic tapes to other magnetic influences. "The most dangerous sources of magnetic stray fields typically found in audiovisual archives are dynamic microphones, dynamic head phones, loudspeakers and moving coil instruments (level meters)."³⁸ Magnetic board stickers should not be used and magnetic media should be kept at the greatest possible distance of lightning conductors.³⁹ There is no risk in using metal storage shelves, as long as they are neither magnetized nor a part of the previously mentioned lightning conductor system.⁴⁰ Overall, "even minor damage or contamination can have major impacts on signal irretrievability," making proper storage and handling of DATs crucial.⁴¹

Evaluation of Physical State of Collection There are several preservation evaluation guides available to assess the current status of audio holdings. Given the precarious nature of the format and the obsolescence of players, these evaluations will allow the holding institution to decide which collections assume priority for conversion and which collections need to be re-housed or conditions re-adjusted.

Storage and Handling

DATs should be stored in an environment that balances Relative Humidity (RH) levels and temperature and is well ventilated. The *Image Permanence Institute Media Storage Guide* advises, based on ISO 18923 recommendations, that for a maximum temperature of 52 degrees the maximum RH should be 50 percent, for a maximum temperature of 62 degrees the maximum RH should be 30 percent, and for a maximum temperature of 73 degrees the maximum RH

³³ George Blood phone interview.

³⁴ Schuller, 6-7

³⁵ Schuller, 10.

³⁶ Schuller, 10.

³⁷ Schuller, 12.

³⁸ Schuller, 13.

³⁹ Ibid.

⁴⁰ Ibid.

⁴¹ Kevin Bradley, editor, *IASA-TC 04: Guidelines on the Production and Preservation of Digital Audio Objects*, Aarhus, Denmark: International Association of Sound and Audiovisual Archives (IASA), 2004, 35.

should be 20 percent.⁴² If binder degradation or mold is present, DATs should be stored at a low temperature with 30 percent to 50 percent RH.⁴³ Cold and frozen temperatures are not recommended as they can lead to lubricant separation and exudation.⁴⁴ It should be kept in mind, as with other audio/visual media, even if stored in the ideal conditions, DATs will still deteriorate, just at a slower rate than less ideal temperatures/humidity settings. Tapes should also be stored upright. DATs are most physically vulnerable when threading; therefore the tapes should either be stored in the rewound or wound position.⁴⁵ It should be noted that some DAT players, however, do not automatically wind past the latest audio recording point.⁴⁶

Cleaning Tapes were marketed alongside DATs and machines in order to remove some of the danger of damage to the tape surfaces and of the magnetic deterioration of the tape.⁴⁷ There is debate among audio engineers and other specialists about the benefits of these tapes, which are quite abrasive on the DAT heads.⁴⁸ If employed, cleaning tapes should be used every 20 to 30 hours of audio.⁴⁹ These cleaning tapes should not be considered an alternative to manual cleanings, however. Servicing of DAT machines should be done regularly, their frequency depending on the duration of use and the starting condition of the machine and the DATs played. There are special flat cleaning swabs made for cleaning video machines that can be used to clean the helical scan heads. The swabs are less abrasive than the cleaning tapes and can remove any loose material that might be clogging the heads.⁵⁰ Any technician that has experience cleaning video players should be able to handle cleaning a DAT machine. Though to ensure greatest possible longevity of the DAT machine, a trained technician should be utilized in order to not only properly clean the machine, but also address any other issues and hopefully spot future ones. One opinion is that DAT machines should be professionally serviced every 1,500 hours or about once a year, unless there are problems.⁵¹

Playback

The use of old or poorly maintained DAT machines might severely deteriorate or destroy any tape played.⁵² However, even fully functioning machines can have trouble playing certain DATs. If the DAT machine was misaligned during recording, any DAT player must be so aligned in order to play the affected DATs.⁵³ Therefore, DAT machines should be properly assessed, set-up, and aligned by experts prior to playback or conversion.⁵⁴ Also, playing back a DAT recorded on a machine produced by a different company than that of the DAT player might result in the

⁴² Adelstein, 7.

⁴³ Adelstein, 2.

⁴⁴ Adelstein, 7.

⁴⁵ Schuller, 11

⁴⁶ George Blood phone interview. For Panasonic Professional Digital Audio Tape Recorder SV-3800, using the jog wheel should allow for winding past the latest audio recording point.

⁴⁷ Ibid.

⁴⁸ George Blood is against the use of cleaning tapes; Pete Reiniger is for their use.

⁴⁹ Pete Reiniger email correspondence.

⁵⁰ Pete Reiniger email correspondence.

⁵¹ George Blood email correspondence.

⁵² Schuller, 15.

⁵³ Richard Hess, "Restoration Tips & Notes: Formats & Resources," <http://richardhess.com/notes/formats/magnetic-media/magnetic-tapes/digital-audio/>

⁵⁴ Schuller, 15.

tape might not being able to track properly.⁵⁵ Therefore, it might be beneficial, if possible, to have several DAT machines to mitigate any problems caused by such issues. Also, if problems occur with a tape (outside of being jammed in the machine), fast-forwarding and then rewinding might help, as it syncs the tension of the tape with that of the machine.⁵⁶ If the tape does become jammed during payback, the machine should be stopped, shut down, and serviced immediately.⁵⁷

Many DAT machines have the ability to display the error correction for the tape being played. Error correction happens regularly, as is the case with most digital transfers. First, the machine creates a checksum for the digital information on the tape. During playback another checksum is generated. If at any point the two do not match, an error has occurred, it is displayed, and the machine attempts to correct it. Most of the time, the machine can correct the error and the playback of the tape runs smoothly. The most common errors for DATs are drop-outs (mutes) and zippers (strings of small errors).⁵⁸ These are usually very noticeable. If the error rate becomes unusually high, the machine should likely be cleaned/serviced.

Unfortunately, as with other digital audio or video recordings, DATs degrade in a much different manner than analog formats. With analog audio or video, as the signal to noise ratio decreases, so does the quality of the playback (usually resulting in pops and hisses in audio and “snow” for video. The recording can still be played back and recovered, just at a much lower quality than originally. With DATs and other digital formats, however, the playback quality remains the same even with the decrease in the signal to noise ratio. Once the ratio drops below the critical level that digital error correction can handle, though, the signal is completely unrecoverable. This makes the timely conversion of DATs critical to the preservation of the audio information stored on them.

Conversion

Though previously lauded as master copies given their digital nature and lossless encoding, the information stored on DATs in archives, production studios, or elsewhere is in danger of becoming irretrievable given the physical problems of the media and as DAT machines were discontinued in 2005, making them difficult to obtain in pristine working condition. In terms of what format to convert to, there is “general agreement that data file formats are preferable to physical carriers containing digital audio streams...for ensuring data security, monitoring data integrity, and managing preservation assets.”⁵⁹ There are many facets of this process, including the selection of hardware, software, file formats, and metadata. Adding to the difficulty is the lack of standards and guidelines for digital-to-digital, rather than analog-to-digital, conversion. The conversion of DATs also must occur in real time, causing the process to be quite time consuming depending on the number of tapes to be converted. Furthermore, depending on the sampling rate, bit-depth, and file format chosen, the digital audio files can take up a great deal of

⁵⁵ Pete Reiniger email correspondence.

⁵⁶ George Blood phone interview.

⁵⁷ Ibid.

⁵⁸ Ibid.

⁵⁹ Mike Casey and Bruce Gordon, *Sound Directions: Best Practices for Audio Preservation*, 33.
<http://www.dlib.indiana.edu/projects/sounddirections/papersPresent/index.shtml>

storage space. These issues of time and storage space should be taken into consideration before any DAT conversion project is undertaken.

The IASA states in *TC03: The Safeguarding of the Audio Heritage: Ethics, Principles and Preservation Strategy* that it is “mandatory that transfers made from old to new archive formats be carried out without subjective alterations or ‘improvements,’” in order to capture the totality of the sound document (including distortion/noise).⁶⁰ And, as in all areas of an archive, documentation for transparency of procedures and guidelines employed in the conversion process (for use by users and future archivists) should be created along with the conversion process. Though with digitization or digital-to-digital transfer there is always the possibility of future conversion to a better digital file format, each transfer should be carried out to the highest standards possible at the time, because this very well may be the last transfer from the original.⁶¹

Analog-to-Digital vs. Digital-to-Digital Conversion

One of the main differences between digital-to-digital conversion and analog-to-digital conversion is the limitation of sampling rate and size. As the information contained in DATs is in a digital format, the audio information is already captured in a discrete signal. Converting from an analog recording (continuous signal) to a digital recording would necessitate sampling at a high enough frequency and bit depth to ensure as much of the continuous signal is captured, limiting the amount of interpolation performed. IASA *TC04: Guidelines on the Production and Preservation of Digital Audio Objects* recommends at least 48 kHz sampling rate with a 24-bit sampling size, with the suggestion of 96 kHz sampling rate and 24-bit sampling size.⁶² Unfortunately, this standard is just not possible for digital-to-digital conversion. Though most DATs were recorded at lower sampling frequencies and sizes than the minimum archival guidelines for audio, there is nothing gained in sonic quality from sampling at a higher rate or size when converting.⁶³ In fact, sampling at a higher rate or depth might introduce noise to the file. Therefore the digital files created from the DAT recordings should be captured at their original settings (likely 44.1 or 48 kHz and 16-bit depth).

Positively, however, digital-to-digital conversion is lossless and likely does not require the extreme recording conditions advocated for analog-to-digital conversion. A seminal piece on audio preservation, *Sound Directions*, suggests that audio engineers and technicians should be used to ensure proper and full-information transfer.⁶⁴ Along with these professionals, the transfers should occur in an “appropriately designed, critical listening environment” or, if not available, “a room that is quiet” where the archivist/technician is aware of its “sonic deficiencies.”⁶⁵ Within this audibly sterile environment, every piece of equipment must be properly tested and calibrated beforehand and the signal from the machine to the analog-to-digital convertor should be as clean and direct as possible, allowing for monitoring and instant

⁶⁰IASA, “TC03: The Safeguarding of the Audio Heritage: Ethics, Principles and Preservation Strategy,” Version 3, December 2005, 7. http://www.iasa-web.org/downloads/publications/TC03_English.pdf

⁶¹ Ibid.

⁶² Bradley, 35.

⁶³ Pete Reiniger email correspondence.

⁶⁴ Casey, 14.

⁶⁵ Casey, 16.

analysis of the signal along every part.⁶⁶ This process, along with the purpose of the created files, should be documented in specific, written guidelines.⁶⁷

Though these recommendations might be especially critical for analog-to-digital conversion (or digital-to-analog-to-digital), it is likely not as essential for digital-to-digital transfer and, in fact, might be out of the budget range of many institutions. As long as the proper hardware, digital connection, and software are used, the conversion of the digital audio information from DATs to digital files should be lossless and accurate. On the other hand, though perhaps not as necessary as for analog-to-digital conversion, it would likely be beneficial to have the same listening environments when listening to the original, the conversion, and the produced master copy, as well as audio/computer engineers or technicians available for consultation.

Conversion Process

The information can be transferred into a computer-based hard drive system either through digital-to-analog-to-digital conversion or digital-to-digital conversion. With the former, the middle step to analog will cause some information loss. It is best to transfer by the latter using an AES/EBU digital connection.⁶⁸ The AES/EBU is a digital audio standard for transporting signals between devices.⁶⁹ The AES/EBU digital output of the DAT player is connected directly to one of the AES/EBU inputs on the computer.⁷⁰ While AES/EBU digital connections are more common in professional equipment, S/PDIF (Sony/Philips Digital Interconnect Format, a data link layer protocol quite similar to AES/EBU) was developed for consumer use and might also be used depending on the hardware used in the conversion process.⁷¹

Conversion Hardware

The computer chosen to undertake the conversion process should have enough RAM and powerful enough CPU to be able to run the selected audio editing software and perform the uptake without adding noise to the track.⁷² The DAT machine chosen, as previously mentioned, should be in excellent working condition, properly aligned, and cleaned prior to beginning the conversion process.

Conversion Software

Audio editing software is available, both free and open-source, as well as for sale, in order to bring in the digital recording and convert to an acceptable file format. Such software should be able to handle at least the sample frequency and bit depth of the original DAT. The software should also be able to stream in the audio as-is, support the selected digital file format and any editing the institution wishes to perform on copies made from the master file (eliminating distortion/noises, trimming tracks, etc.).

File Formats

When processing DATs, it is best to convert the originals into uncompressed audio file formats,

⁶⁶ Ibid.

⁶⁷ Casey, 45.

⁶⁸ "Digital Audio Tape," Wikipedia. http://en.wikipedia.org/wiki/Digital_Audio_Tape

⁶⁹ "AES/EBU," Wikipedia. <http://en.wikipedia.org/wiki/AES/EBU>

⁷⁰ Casey, 23.

⁷¹ "S/PDIF," Wikipedia. <http://en.wikipedia.org/wiki/S/PDIF>

⁷² Audacity Version 1.2 Manual, <http://audacity.sourceforge.net/manual-1.2/prefs.html>

as they are the most accurate digital representation of a sound wave, as well as for their ability, as previously mentioned, to ensure data security, monitor data integrity, and preservation management. Uncompressed audio file formats are "wrapper formats that use Pulse-Code-Modulation (PCM) audio as their raw material and add additional data so that it is compatible with codecs" and operating systems.⁷³ Codecs (coder-decoder) are programs with encode/decode data, and come into play with the selection of best file formats. If uncompressed formats are not viable, for compressed formats lossless data compression is the least destructive as it uses a mathematical algorithm to encode the data so that it can be decoded without any audio degradation; however, it requires an encoding and decoding stage and that suitable software is available to the user.⁷⁴ FLAC is one such open-source lossless compression codec available, which is widely used and gives the best long-term outlook for compatibility and support.⁷⁵

Certain sustainability factors should be considered when choosing an acceptable file format. The Library of Congress has recommended looking at these areas in particular as they heavily influence the feasibility and cost of preservation: the disclosure of documentation related to the format; how widely the format has been adopted; the transparency of the format; self-documentation; external dependencies; impact of patents; technical protection mechanisms; and fidelity. The formats with more accessible documentation, widespread adoption, transparency, and self-documentation and the least dependence on external software/hardware and patents will be the ones least likely to become obsolete (at least in the short-term) and the most likely to be more secure and have tools for (easier) validation, migration and emulation.⁷⁶

WAV

The Microsoft Wave format (WAV) is the audio format of the Windows operating system. It is a flexible format that is able to store very high quality audio, but it is limited to 4 GB and does not have the ability to contain any metadata describing the audio contents.⁷⁷ WAV is a subtype of RIFF (Resource Interchange File Format), which is a file structure for multimedia resource files.⁷⁸ It is supported on almost all computer systems.⁷⁹

The Library of Congress lists WAV as the preferred format for sound recordings, and is considered the best digital format for most of the audio converted for American Memory.⁸⁰ The Library of Congress rated WAV (and BWF – see below) high in terms of transparency, adoption, disclosure, and fidelity tests. However, BWF is considered better than WAV in terms of self-documentation.⁸¹

⁷³ "Uncompressed Audio File Formats," JISC Digital Media.

⁷⁴ Ibid.

⁷⁵ "Uncompressed Audio File Formats," JISC Digital Media.

⁷⁶ "Sustainability of Digital Formats," Library of Congress,
<http://www.digitalpreservation.gov/formats/sustain/sustain.shtml>

⁷⁷ "Uncompressed Audio File Formats," JISC Digital Media.

⁷⁸ "RIFF (Resource Interchange File Format)," Sustainability of Digital Formats, Library of Congress,
<http://www.digitalpreservation.gov/formats/fdd/fdd000025.shtml>

⁷⁹ "File Formats," Audacity v.1.2 Manual.

⁸⁰ "WAVE Audio File Format with LPCM Audio," Sustainability of Digital Formats, Library of Congress,
<http://www.digitalpreservation.gov/formats/fdd/fdd000002.shtml>

⁸¹ Carl Fleischhauer, "Sound Savings: Preserving Audio Collections,"
http://www.arl.org/preserv/sound_savings_proceedings/Digital_audio.shtml

BWF

The IASA and AES recommend the Broadcast Wave Format (BWF or WAV) for use in archives. BWF is an extension of the WAV format (therefore functionally identical and cross compatible), though it contains an extra header for the inclusion of metadata, either the BEXT chunk or, an iXML chunk (an XML metadata schema that supersedes BEXT).⁸² It is non-proprietary, restricted in definition, has a sample-accurate time stamp, and contains assigned locations for specific metadata. The restriction refers to the fact that BWF only contains either MPEG or PCM audio, while WAV can have any of several codecs.⁸³ DATs, though, use PCM, which means that it is possible (given the proper tool – discussed in Appendix E) to transform a WAV created from a DAT into a BWF file by adding the BEXT chunk.

The Federal Agencies Audio-Visual Working Group has issued a set of guidelines for embedding metadata in digital audio files, particularly Broadcast WAVE files. They strongly recommend, and would require, if they had the authority to do so, populating the data elements of Originator, Originator Reference (principle or “best” identifier), Description (which can point to additional, external metadata), Originator Date, and Version (of BWF). The elements Time Reference, Origination Time, and Coding History are recommended, but deemed optional.⁸⁴

The Library of Congress cites BWF as the preferred master format for mono/stereo audio.⁸⁵

AIFF

The AIFF (Audio Interchange File Format) is the default uncompressed audio format on Apple computers and is therefore “widely adopted by Apple users engaged in professional audio work”⁸⁶ It is similar to WAV, but “uses a different method of dividing the PCM data into manageable chunks.”⁸⁷ AIFF is the preferred master format of the Harvard University Library Digital Initiative for audio reformatting.⁸⁸ AIFF is functionally equivalent to WAVE_LPCM.⁸⁹

Other File Formats⁹⁰

The Library of Congress Digital Preservation – Sustainability of Digital Formats website lists several other digital file formats that are acceptable for mono/stereo. These include:

- MP3_FF, MP3 File Format
- AAC_ADIF, Advanced Audio Coding (MPEG-2), Audio Data Exchange Format
- AAC_M4A, Advanced Audio Coding (MPEG-4), m4a File Format

⁸² “Uncompressed Audio File Formats,” JISC Digital Media.

⁸³ Ibid.

⁸⁴ Federal Agencies Audio-Visual Working Group, “Embedding Metadata in Digital Audio Files,” 2009.

⁸⁵ “WAVE_LPCM_BWF, Broadcast WAVE Audio File Format,”

<http://www.digitalpreservation.gov/formats/fdd/fdd000003.shtml>

⁸⁶ “AIFF File Format with LPCM Audio” Sustainability of Digital Formats, Library of Congress,

<http://www.digitalpreservation.gov/formats/fdd/fdd000116.shtml>

⁸⁷ “Uncompressed Audio File Formats,” JISC Digital Media.

⁸⁸ “AIFF File Format with LPCM Audio,” Sustainability of Digital Formats, Library of Congress.

⁸⁹ Ibid.

⁹⁰ “Sound – Preferences in Summary,” Sustainability of Digital Formats, Library of Congress,

http://www.digitalpreservation.gov/formats/content/sound_preferences.shtml

- QTA_AAC, QuickTime Audio, AAC Codec
- WMA_WMA9_PRO, Windows Media Audio File with WMA9 Professional Codec
- WMA_WMA9, Windows Media Audio File with WMA9 Codec

File Names and Metadata

Complete, authoritative metadata cannot and should not be confined to the file header of the created digital file, there should always be an external metadata creation and storage system.⁹¹ Furthermore, *Sound Directions* warns "while file names can be convenient and reflect catalog and preservation workflow, they should be structured, consistent, well-formed, and not used as a database for cataloging or for other metadata."⁹² File names should use ASCII letters, digits, underscores, and hyphens, but avoid diacritic marks, non-printing characters, values that might change over time, and use of the period before the file extension at the end of the file name."⁹³ Also, identifiers used in the file name should correspond to those used with the physical objects and in catalogs.⁹⁴

IASA TC03 recommends that preservation metadata should contain complete information on the original carrier, format, and state of preservation, replay equipment and its parameters for the original, the digital resolution, file format information, and all equipment used, the operators involved in the process, a checksum, and details of secondary information sources.⁹⁵

See Appendix E for documentation regarding FADGI's recommendations.

Validation

As with other digital files held in an archive, the digital file created by the conversion process should be checked regularly to ensure data integrity.⁹⁶ Any changes to the checksums or files should be properly noted in the metadata and made readily available in order to ensure authenticity of the primary data for users and future archivists.⁹⁷ Furthermore, it is best to have several copies of the digital files stored in separate locations in order to protect against disasters, both physical/natural and data corruption.

Past and Current Conversion Projects

Individual research has only uncovered one organization, the National Security Archive, which has somewhat haphazardly converted, through the help of research associates and volunteers, a large number of DATs in their collection. Professor Luke Nichter, one of these researchers, used Audacity audio editing software, primarily due to the fact it was free and open-source and relatively easy to use. However, Nichter was disappointed that Audacity did not offer batch conversion. For the process he used a TASCAM DA-302 DAT machine connected to a PC with an Edirol USB digital-to-digital interface. However, though Nichter created two master WAV copies (one for his use and one backup) from which he created MP3 use copies, it does not seem

⁹¹ Casey, 38.

⁹² Ibid.

⁹³ Casey, 52.

⁹⁴ Ibid.

⁹⁵ IASA, TC03, 11.

⁹⁶ IASA, TC03, 9.

⁹⁷ IASA, TC03, 5.

that his original intention was the creation of preservation quality master copies. Also, he did not really add metadata to the files, though he says he usually does when posting a collection of audio files to his website (www.nixontapes.org). The only problems Nichter encountered included the file size of the converted tapes, which, when multiplied over hundreds of hours of audio, proved to take up approximately 3 terabytes. Although he could handle the sizes produced by WAV or AIFF, he recommends FLAC as a file format that is about half the file size of WAV with no discernable (to him) difference in quality. For quality assurance Nichter just listened to the beginning and end of each file and did a rough inspection of the audio histogram in Audacity to ensure that it looked like what it was supposed to, and to locate areas he wanted to “normalize.”⁹⁸

George Blood at Safe Sound Archive was consulted via email and telephone in July 2010. Safe Sound varies the equipment they use for conversions based on the nature of the materials submitted and their condition. Usually they use hardware and software made by MetricHalo, which can only be used on a Mac. They also have a tool that can extract DATs as data and can do so faster than real time; however, it is a difficult tool that requires operation by experts. In qualifying and testing systems, they record each tape twice and check the two tracks against one another; however, while this can be highly reliable it can be complicated and takes a great deal of effort. Safe Sound has received DATs primarily from music collections (for example, Curtis Institute of Music) and oral history collections (Columbia University).⁹⁹ George concurred that few institutions are doing in-house conversion of DATs; he only remembered Democracy Now as taking on a similar project. Democracy Now was contacted about their process and equipment, but as of the end of August 2010 they had not responded.

There are several vendors that convert audio/visual holdings (including obsolete and damaged formats) or repair DAT machines.

Smithsonian Institution Archives DAT Pilot Project

The Smithsonian Institution Archives (SIA) DAT Pilot Project began in earnest in June 2010. The project began using a Mac Pro 4.1 equipped with Audacity 1.2.5 (free and open-source) audio editing software in SIA's Audio-Visual Preservation Lab. SIA chose to use Audacity due to previous projects had used it and it is free and open-source. Though Audacity does not support 24-bit depth, as DATs are either 12- or 16-bit, this is not a problem.¹⁰⁰ The DAT reader is a Panasonic Professional Digital Audio Tape Recorder SV-3800 borrowed from Pete Reiniger from Smithsonian Folkways, who also provided a cleaning tape. The two pieces of hardware are connected through the AES/EBU IEC Type II optical output from the DAT machine to the S/PDIF optical input on the Mac.

The WAV format was chosen as the best format to export as because Audacity supports this format (and not BWF, which is the recommended master format), as well as limitations in storage space and funds. Other audio editing software options have been researched over the course of this project. Despite the abundance of audio editing software, certain stipulations (such

⁹⁸ Luke Nichter email correspondence.

⁹⁹ George Blood email correspondence.

¹⁰⁰ George Blood email correspondence.

as compatibility with Mac OS X and able to export to the WAV format) have limited what products are acceptable for this project. George Blood at Safe Sound Archive recommended a tool available that can convert WAV-PCM files into BWF files. With such a tool, the files converted using Audacity can be transformed into BWF files.¹⁰¹ See Appendix D for details and documentation. Such a tool would mean that either SIA can continue to use Audacity and add the BEXT chunk using this tool in order to preserve in the preferred format, or SIA can use other software once it is available to export directly as BWF and use the tool to transform just the files created using Audacity in the early stages of the pilot project.

External metadata was created for each tape and stored in one Excel spreadsheet. See Appendix C for fields. The files created, along with the Excel spreadsheet, were saved on the archive's server. For quality assurance, each file, downloaded from the server, was listened to in its entirety using iTunes. Checksums were also run on each file using Harvard University Library's File Information Tool Set (FITS) and stored in a separate folder within each box folder.

The first collection transferred was Accession 04-062, Smithsonian Productions, Productions 1991-2001, Box 7. This Smithsonian Productions collection includes DATs, as well as other formats such as High-8s, that contain recordings of broadcasts and sessions of the radio program Jazz Smithsonian, as well as recordings of concerts of the Smithsonian Jazz Masterworks Orchestra. At the beginning of the project, several tests were done in order to assess the various audio settings, particularly bit depth, in Audacity. Several settings caused Audacity to crash,¹⁰² while several led to moderate to severe distortion.¹⁰³ This testing, plus further research into the software led to the selection of specific settings, which are listed and explained in Appendices A and B.

However, after the conversion of a few tapes in Box 7, slight blips (similar to the sound of someone lightly brushing a microphone) could be heard in the playback. Again several tests were conducted in order to narrow down a cause.¹⁰⁴ Each test contained these small blips, despite the differing settings and environments, though the blips did not occur at the same points between the different tests. This phenomenon could be attributed to the fact that the output is being put through the Mac's internal speakers (rather than through headphones, as the originals were monitored) or noise sensitivity on the part of the archivist. Headphones were ordered to help combat the effects of the former and hopefully provide a more consistent listening environment for the latter. Once headphones arrived, the noise could no longer be heard.

Another issue was track volume. When listening to the WAV file, the track volume, particularly when there is talking (versus music), is often quite low. However, the input volume is at 100%

¹⁰¹ George Blood email correspondence.

¹⁰² 24-bit Default Sample Format with signed 24-bit PCM Uncompressed Export Format.

¹⁰³ 32-bit float Default Sample Format with signed 2-bit PCM Uncompressed Export Format would not play; 24-bit Default Sample Format with signed 16-bit PCM Uncompressed Export Format; 32-bit float Default Sample Format with 32-bit float Uncompressed Export Format; and 32-bit float Default Sample Format with signed 24-bit PCM Uncompressed Export Format all caused distortion.

¹⁰⁴ Tests include recording with: other applications open concurrently, no applications open/movement of mouse, varying levels on the DAT machine headphones, High-quality Dither set to none, and Default Sample Size set to 16 bits.

on Audacity and it appears as though the track volume cannot be enhanced without editing/processing the track, which goes against the goal of the creation of a preservation master as-is copy and can possibly cause dithering. This does not appear to be an issue, however, in the completely edited program masters and air copies of Jazz Smithsonian shows.

For this first accession/box, 46 tapes were converted, requiring 31.44 GB of storage space on the server. Several tapes had points of distortion, cut-outs, and pops, which were then carried over to the WAV files; however, only two WAV files contained pops not present in the original and these occurred at 0:00 and 0:04 respectively, well clear of any important audio, and therefore do not affect the quality of the recording. The cleaning tape provided by Pete Reiniger was used after approximately 25-30 hours (halfway through the box). Also, there were two errors in the finding aid concerning identifiers for tapes JS95OS0284 (identifier on tape, finding aid has an M not an S) and JS95OM0294 (identifier on tape, finding aid has an S not an M). These were noted and the finding aid should now be correct.

The second collection processed was 06-181, Smithsonian Productions, Productions 1994-2000, Box 1. This box contained 16 tapes and uses 10.01 GB of storage space. Similar to the first collection, this accession/box contained recordings created during the production of episodes of the radio show Jazz Smithsonian. Unlike the first collection, these tapes did not have unique identifiers outside of their finding aid descriptions. Therefore, short identifiers were created based on these descriptions, focusing especially on dates, and the number and order of the tapes.¹⁰⁵ Tapes SJMO_11151997_8, SJMO_11151997_9, SJMO_0507_0508_14, and SJMO_Originals_16 had to be redone due to mild distortion not present in the original. This noise was noticeable within the first few minutes of listening back to the file. Once redone, all four files were audibly identical to the originals.

The third collection was accession 06-272 Smithsonian Productions, Productions 1992-2000, Box 1. This box contained 10 DATs that featured recordings created during the production of the CDs, "Heartbeat: Voices of First Nations Women" and "Heartbeat 2" (1998) produced for Smithsonian Folkways. Several of these tapes were originally recorded in 48 kHz, so this was set as the sample rate in Audacity. These files were saved in DATs within Box 1 in the "Preserved" section of the Accession 06-272 folder. Low speaking volume was especially prevalent in this collection, though that is likely due to the set-up of the recording session, i.e., people not talking directly into microphones or not enough microphones for participants. These tapes require 4.97 GB of storage space.

Finally, Box 9 of the first accession, 04-062, was transferred. This box held 18 DATs, which required 10.17 GB of space. During the course of transferring these tapes, "cleaning" kept flashing during points of distortion on the DAT machine display. Therefore, the cleaning tape was used before recording JS96PM0245. Distortion not present in the original was prevalent in JS95AC0213, however, as this tape was a safety copy of JS95PM0212, the transfer was not redone.

¹⁰⁵ For example, identifier SJMO_06211996_1 was created from this finding aid description: Smithsonian Jazz Masterworks Orchestra, Fanfare, 6/21/1996, DAT.

Between June and August 2010, 87 DATs (a little over 89 hours) were transferred, requiring 56.59 GB of storage space. During this time, Audacity only froze five times after 30-plus minutes of recording, usually due to other programs running concurrently. Furthermore, only four tapes had to be re-transferred due to distortion/noise on the recording that was not present in the original, while one file that contained distortion not present in the original was not redone as it was already a safety copy of another tape. Along with this report, a DAT to WAV How-To guide was created and stored on the archive's server for reference for staff/volunteers/interns.

Recommendations for Proceeding

Though researching Digital Audio Tapes has been difficult due to the fact that the information on the format and standards/guidelines for their preservation and conversion is quite disparate, this pilot project has a very positive outlook. First, the conversion process is quite straightforward hardware-wise; requiring only one DAT machine and one Mac in the Audio/Visual Preservation Lab. Second, the current audio editing software employed, Audacity, is easy to use and so far has been producing good quality digital files. Only five out of 87 tapes (about 6 percent) processed had to be redone and there were software problems/freezes with only 6 out of 87 tapes (about 7 percent), bringing the total error percentage for the summer to only 13 percent. This is good news for creating a more efficient QA process. In each of the five tapes that were redone, it was evident within the first five minutes that this distortion was present. Therefore, while Audacity is being used to create the WAV files, QA can probably be reduced to sampling the first five minutes, five minutes in the middle, and the last five minutes of a recording. Or, perhaps, one can listen to the beginning and then fast forward through the track in iTunes, stopping occasionally to listen for distortion/issues. However, it should be noted that the archivist/user should listen to the entire recording while it is transferring in order to quickly address any software or hardware problems and to note any distortion/noise in the original.

Third, the DATs themselves have all been in great condition. This might change in the future as different collections are processed, but so far no condition issues have had to be addressed. Along the same lines, while the DAT machine appears to be in great working order now, Pete Reiniger admitted that it had not been manually cleaned by a technician in a while due to low use. If SIA is to continue this project for longer than a year, having the machine serviced should be looked into. Fourth, the use of commercially available software could greatly improve the areas, though few, that are less than ideal in this project. These areas are the use of WAV instead of BWF (and thus the need for an extra step to embed the BEXT chunk) and the lengthy QA process. In the meantime, the QA time can be reduced as previously mentioned and more research can be put into this BWF MetaEdit tool to, hopefully, batch process the WAV files as efficiently as possible. Despite the difficulty in researching the medium and conversion process, the actual process of transferring the DATs held in the archive has been largely uncomplicated and is most definitely a project that SIA can successfully continue.

Appendix A

Mac Pro 4.1

Audio Settings

The computer, a Mac Pro 4.1, used in the digital-to-digital conversion and playback needs its audio settings correctly set. For the Mac, accessing the Audio MIDI Setup in the Utilities folder will allow changes to the audio input and output settings. The input should be set to the correct source, which for this project is 'Digital Input,' and output, 'Built-in Output' (internal speakers). The format should be set to the sample rate (44.1 or 48 kHz) of the original and the proper bit rate (2 channel, 16 bit) for both input and output.

Appendix B

Audacity Audio Editing Software Version 1.2.5

Preference Settings¹⁰⁶

Audio I/O:

Playback Device

Built-in Output should be selected if listening to the playback through the computer's internal speakers or through headphones.

Recording Device

Built-in Digital Input should be selected as this project is using a digital-to-digital connection.

Recording Channels

Audacity offers several different channel options. As DATs are recorded in stereo, 2 (Stereo) is the proper setting for this project.

Check Selections

'Play other tracks' allows the user to record multiple tracks over top of each other, one at a time. As this project is creating preservation master copies of recordings, this box should remain unchecked.

'Hardware playthrough' (only available for Macs) allows the computer to send the sound being recorded directly back out through the speakers. This takes no extra CPU and has no latency; however, it is only possible if the input and output are on the same audio device, which for this project it is not, and the device is able to do so.

'Software playthrough' allows the user to hear what is being recorded by taking the data about to be recorded by Audacity and playing it out through the sound card or a combination of sound devices. Neither this nor the previous setting should be checked, as the user should be listening to the original recording being played by the DAT machine during transfer.

Selecting 'Do not modify audio device settings (such as sample rate)' means that Audacity does not modify the settings on other applications found on the computer running Audacity.

Quality:

Default Sample Rate

The Default Sample Rate controls the sample rate of new projects. The default of Audacity is 44.1K Hz. With digital to digital conversion, copies cannot be made of tracks at higher sample rates than the originals. As DATs can only record in 32 kHz (with 12-bit), 44.1

¹⁰⁶ Audacity v.1.2. Manual, <http://audacity.sourceforge.net/manual-1.2/> and Audacity v.1.2.4 Online Help, <http://audacity.sourceforge.net/onlinehelp-1.2/reference.html>.

and 48 kHz (with 16-bit), the preservation master copies made will either be in 44.1 kHz or 48 kHz (the most common DAT sample rate), depending on the original.

Default Sample Format

The Default Sample Format controls the default format used to store audio samples.¹⁰⁷ Audacity's 32-bit float sample size has "almost infinite dynamic range," however; it takes up twice as much storage as 16-bit samples. DATs can only allow sampling in 12-bit (for only 32K Hz) or 16-bit. As this project is creating preservation masters, '32-bit float' is the best setting in Audacity for intake, though the files will be exported in 16-bit due to storage restrictions. Since no processing/editing will be taking place, there should be no dithering (addressed in a later setting).

Real-time Sample Rate Converter

Real-time Sample Rate Converter (Audacity has more than one) is used when there is a track that is not the same sample rate as the copy being made. This only applies to real-time playback. Fast Sinc Interpolation completes the waveform data by estimating missing values (when converting from a lower sampling rate to a higher one). Sinc refers to the particular interpolation method (and mathematical equation) used.¹⁰⁸ There appears to be some debates in online forums as to whether Audacity's Sample Rate Converter (SRC) is of acceptable quality compared to other audio editing software. However, as digital-to-digital conversion does not allow for sampling at a higher rate than the original recording, the master preservation copies will be the same sampling rate (32 kHz, 44.1 kHz or 48 kHz) as the original track. For this reason, the sample rates for the DATs do not need converting, making this setting unimportant to this project.

High-quality Sample Rate Converter

High-quality Sample Rate Converter is similar to Real-time Sample Rate Converter; however, it only applies during Export and mixing. Again, as DATs only record at 32 kHz, 44.1 kHz or 48 kHz, sample rates for the preservation masters will be the same as the original recordings. Therefore, there will be no need to convert the sample rate, making this setting superfluous for this particular project as well.

Real-time Dither

Dithering is used when converting a track with a high sample size (a lot of dynamic range) to a copy with a lower sample size (less dynamic range). "A small amount of dithering can make the audio sound a little bit better, but it can also slow down processing a little bit."¹⁰⁹ This only applies for real-time playback. Also, as we have '32-bit float' as the sample format setting and DATs are either 12 or 16-bit, there will be no conversion from a high sample size to a lower sample size in terms of real-time playback, so no dithering should occur.

High-quality Dither

¹⁰⁷ Audacity v.1.2.4 Online Help

¹⁰⁸ "Sample Rate Conversion," Wikipedia. http://en.wikipedia.org/wiki/Sample_rate_conversion

¹⁰⁹ Audacity v.1.2.4 Online Help

High-quality Dither is similar to Real-time Dither; however, it only applies during Export and mixing. Currently, Audacity has been set to export as 16-bit PCM WAV format, while the Default Sample Format is set as '32-bit float.' This conversion will be between 100 percent and 99.975 percent lossless. If dither is set to 'none,' then conversions will be done by simple rounding. Setting dither to 'rectangle,' 'triangle,' or 'shaped' will apply a very small amount of noise to the signal based on the particular mathematical formula for each type. According to the Audacity manual, in order to prevent dithering, tracks should be exported as either '24-bit PCM,' if available, or '32-bit PCM' WAV format. Such a setting would mean the conversion is 100 percent lossless and so no dithering would be applied.¹¹⁰ However, similar to the sampling rate, in digital-to-digital conversion bit depth cannot be converted, or at least nothing is gained in sonic quality. Also, because this project is importing 16-bit audio, exporting as 16-bit and no editing/processing is being done, no dithering should occur.

File Formats:

Make a Copy should be selected as a precaution when importing files into Audacity.

Uncompressed Export Format

Currently, the correct setting for the project is signed 16-bit PCM WAV.

OGG Export Setup and MP3 Export Setup

As the DATs are being exported into the WAV format, these settings do not apply.

¹¹⁰ "Dither," Audacity Wiki. <http://wiki.audacityteam.org/wiki/Dither>

Appendix C

Metadata

SIA is storing the metadata for the DAT Pilot Project in an Excel for Mac Spreadsheet.

Fields

Accession # / Box #

Title (of the accession)

Description (of each tape, provided by the finding aid for the accession)

Processing Archivist (initials)

Date Processed

Other notes or labels on the tape not on the finding aid

File Name (the identifier from the tape and finding aid)

Media

Duplicate?

Quality Assurance 1 (initials)

Quality Assurance 2 (initials)

Audio Starts

Audio Ends

Comments (about the audio)

Type (broadcast, oral history, concert, other)

SP (Smithsonian Productions) Number – will possibly link the spreadsheet to the database in the future

Issues (concerning the recording process/quality)

Appendix D

WAV to BWF Conversion

The Federal Agencies Digitization Guidelines Initiative (FADGI) created a tool (for PCs), BWF MetaEdit, to check/add metadata to WAV files, as well as to validate files and embed the resulting checksums. This can be used to either add the BEXT chunk to WAV files, transforming them into BWF files, or to check/edit the metadata already embedded in the files. The tool also allows for the information of a file to be exported in a CSV or XML version, edited in that format, and then imported back in to the tool.

The tool is free and open source, and is available for download (PCs only) at
<http://www.softpedia.com/get/Office-tools/Other-Office-Tools/BWF-MetaEdit.shtml>

The document detailing the requirements/recommendations for each element:
http://www.digitizationguidelines.gov/audio-visual/documents/Embed_Guideline_090915r.pdf

Introductory Discussion:
http://www.digitizationguidelines.gov/audio-visual/documents/Embed_Intro_090915.pdf

The Assessment Report and Initial Recommendations:
http://www.digitizationguidelines.gov/audio-visual/documents/AVPS_Audio_Metadata_Overview_090612.pdf

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<http://www.solorb.com/dat-heads/FAQ>

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Richard Hess, personal/professional website, “Audio Tape Restoration, Repair and Mastering

<http://www.richardhess.com/tape/index.htm>

“Digital Audio” <http://richardhess.com/notes/formats/magnetic-media/magnetic-tapes/digital-audio/>

“Restoration Tips & Notes: Formats & Resources,”

<http://richardhess.com/notes/formats/magnetic-media/magnetic-tapes/digital-audio/>

IASA 5.5: Reproduction of Digital Magnetic Carriers

<http://www.iasa-web.org/tc04/reproduction-digital-magnetic-carriers>

IASA-TC 04: Guidelines on the Production and Preservation of Digital Audio Objects.

Aarhus, Denmark: International Association of Sound and Audiovisual Archives (IASA), 2004.

IASA-TC 03. The Safeguarding of the Audio Heritage: Ethics, Principles and Preservation Strategy. Version 3, December 2005.

http://www.iasa-web.org/downloads/publications/TC03_English.pdf

JISC Digital Media

“Uncompressed Audio File Formats,”

<http://www.jiscdigitalmedia.ac.uk/audio/advice/uncompressed-audio-file-formats>

“An Introduction to Digital Audio” <http://www.jiscdigitalmedia.ac.uk/audio/advice/an-introduction-to-digital-audio/>

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https://ccrma.stanford.edu/courses/192b/192b_Lecture_4_06.pdf

NARA. Frequently Asked Questions (FAQ) About Digital Audio and Video Records

<http://www.archives.gov/records-mgmt/initiatives/dav-faq.html>

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<http://www.safesoundarchive.com/index.cfm>

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Sustainability of Digital Formats: Planning for Library of Congress Collections.

<http://www.digitalpreservation.gov/formats/>

“Sustainability Factors” <http://www.digitalpreservation.gov/formats/sustain/sustain.shtml>

http://www.digitalpreservation.gov/formats/content/sound_preferences.shtml

“Sound – Preferences in Summary”

http://www.digitalpreservation.gov/formats/content/sound_preferences.shtml

“WAVE_LPCM_BWF, Broadcast WAVE Audio File Format”

<http://www.digitalpreservation.gov/formats/fdd/fdd000003.shtml>

WAVE Audio File Format with LPCM audio

<http://www.digitalpreservation.gov/formats/fdd/fdd000002.shtml>

RIFF (Resource Interchange File Format)

<http://www.digitalpreservation.gov/formats/fdd/fdd000025.shtml>

AIFF File Format with LPCM Audio

<http://www.digitalpreservation.gov/formats/fdd/fdd000116.shtml>

Wikipedia

“Digital Audio Tape,” http://en.wikipedia.org/wiki/Digital_Audio_Tape

“Aliasing,” <http://en.wikipedia.org/wiki/Aliasing>

“AES/EBU,” Wikipedia. <http://en.wikipedia.org/wiki/AES/EBU>

“S/PDIF,” Wikipedia. <http://en.wikipedia.org/wiki/S/PDIF>

“Sample Rate Conversion,” http://en.wikipedia.org/wiki/Sample_rate_conversion

Other Audio Digitization/Preservation Sources¹¹¹

Association for Recorded Sound Collections <http://www.arsc-audio.org/>

Audio Preservation and Restoration including some links to film and video tape preservation. By John R. Gibbs. University of Washington University Libraries.
<http://guides.lib.washington.edu/AudioPreservation>

Capturing Analog Sound for Digital Preservation: Report of a Roundtable Discussion of Best Practices for Transferring Analog Discs and Tapes. Washington, D.C.: Council on Library and Information Resources and Library of Congress, 2006.
<http://www.clir.org/pubs/reports/pub137/pub137.pdf>

DAT = Digital Audio Tape. <http://audiotools.com/dat.html> Links at the bottom of the page might be useful (for a historical perspective when DATs were in use)

Digital Audio Best Practices Version 2.1. CDP Digital Audio Working Group.
<http://www.bcr.org/dps/cdp/best/digital-audio-bp.pdf>

PrestoSpace digitization and storage guide.
<http://prestospace-sam.ssl.co.uk/>

Sound Savings: Preserving Audio Collections. Proceedings from the Symposium July 24-26, 2003. http://www.arl.org/preserv/sound_savings_proceedings/index.shtml

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http://www.richardhess.com/tape/history/HESS_Tape_Degradation_ARSC_Journal_39-2.pdf

¹¹¹ Either not yet consulted/fully explored or pertain more to analog-to-digital conversion and other areas beyond the scope of this report.