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Technical Committee
Standards, Recommended Practices, and Strategies

Guidelines for the Preservation of Video Recordings

IASA-TC 06

Part C. Introduction

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C.1 INTRODUCTION TO CARRIERS: ASSESSMENT, PREPARATION, AND CLEANING

C.1.1 Background

This section of IASA-TC 06 provides advice on how to replay obsolete videotapes. The guideline's initial edition is limited to tape-based video recordings that are played back in a customary manner, and the following carriers are included:

C.2 Quadruplex 2-inch Videotapes
C.3 EIAJ and Sony CV ½-inch Open Reel Videotapes
C.4 1-inch Helical-Scan Open Reel Videotapes (types A, B, and C)
C.5 U–matic ¾-inch Videocassettes
C.6 ½-inch Analogue Consumer and Semi-professional Videocassettes
C.7 Betacam ½-inch Professional Videocassette Family

All of the video recordings discussed in this initial edition are analogue, with the exception of the later generation Betacam cassettes. Though the need to preserve early generation digital recordings is hardly less pressing, there is a particular logic in dealing with the large quantity of professional and consumer video recordings in analogue format first. In addition, the debate on how to deal with the variety of lossy, compressed digital formats has yet to be played out, and will doubtless be a driver for the next edition of IASA-TC 06.

Each format-based chapter provides advice specific to that particular carrier and the VTRs needed to play those carriers back. There are, however, a number of shared topics and section C.1.3 offers general advice on the assessment, preparation, cleaning, and heat treatment or "baking" of videotapes. Additional carrier-specific advice on these topics, where relevant, will be found in the sections devoted to specific carriers.

C.1.2 Videotape formats, standards, and specifications

There are two classes of standards in play for video recordings. One class concerns the *video signal*, sometimes referred to as *baseband*, produced by playing the tape. Loosely speaking, this can be thought of as a *video stream*, a waveform that represents rapidly changing electrical voltages. As outlined in section B.1.1.3 above, video signal standards have been strongly influenced by the legal mandates that pertain to television broadcasting, which differ in different parts of the world.

The second class of standards governs the ways in which the variations in electrical voltage that comprise the signal are translated into *magnetic fluctuations* captured on the coating on the tape. These fluctuations are represented by multiple *tracks* on the tape, generally in complex patterns that reflect the varying designs of videotape recorders (VTRs), the marketplace products of a very competitive and ever-evolving industry. Examples of these magnetic track patterns are represented by illustrations in some of the subsections that follow.

Over time, as technology evolved, and corporate competition continued, a significant number of videotape types and recording formats came into existence: one website consulted in 2017 offered a relatively comprehensive list of 88 types (Stoffel: 2004), while the *Videotape Identification and Assessment Guide* (Jimenez and Platt: 2004) lists 15 types frequently encountered in memory institution archives. Bodies like SMPTE (Society of Motion Picture and Television Engineers) and the IEC (International Electrotechnical Commission) have standardized many (but not all) of these track-format configurations.

Sidebar: Field Guides to the Tapes: Online Resources with Illustrated Descriptions

This edition of IASA-TC 06 is sparsely illustrated. There are a number of online resources, however, that offer excellent "field guides," pictorial web pages that present images and facts about many videotape formats. The following five are well worth consulting:

Audiovisual Formats: A Guide to Identification, http://calpreservation.org/wp-content/uploads/2013/10/2013-Audiovisual-Formats_draft_webversion-2013oct15.pdf (IASA-TC 06 bibliographic reference: California Audiovisual Preservation Project: 2013)

Find Your Videotape Here, http://www.dcvideo.com/videotape-identifier (DC Video: n.d.)

The Little Reference Guide for Small Video Tape Collections, http://www.little-archives.net/guide/content/home.html (TAPE: 2008)

Video Format Identification Guide, http://videopreservation.conservation-us.org/vid_id/ (Messier and Vitale: 2007)

Videotape Identification and Assessment Guide, http://www.arts.texas.gov/wp-content/uploads/2012/04/video.pdf (Jimenez and Platt: 2004)

More often than not, this second class of standards resulted from lobbying and participation in standards writing by the companies that developed and market the tape formats. To an outsider, this standard-setting process may appear a little like the Wild West, for with videotape recording formats, the standards bodies follow the lead of the manufacturers as the technology and the marketplace evolves. For the manufacturers, this calculation represents a trade-off. On the one hand, standardisation increases adoption by end-users by "freezing" the format specification and encouraging multiple companies to manufacture tapes or VTRs that meet the specification. This, it is hoped, increases sales overall. On the other hand, the public disclosure increases the competition for those sales, although it is also the case that the original developers may hold patents on aspects of the technology that provide them with licensing royalties.

In any case, the outcome of this process is a surfeit of videotape specifications, some governed by standards and some not. For an archive wishing to digitise older tapes in its collections, the organisation (or its supporting contractors) must possess working equipment that meets the relevant standard or specification. This can be challenging and, faced with this requirement, many archivists will take comfort from observations like the one offered by the influential Australian engineer Neville Thiele. In 1979, Thiele wrote an article entitled "The Importance of Standards in Broadcasting," and its introduction describes the tensions that face a standard-setting body that focuses on audiovisual formats.

> Many people think of engineering standards as a dull business, essential perhaps, but dull. Now anyone who has worked on standards will realise that such work, in fact, is anything but dull. It demands first of all, a full understanding of the technology involved, its production in the factory and its use by the consumer, an understanding [of what is] on the one hand desirable and on the other hand technically and economically feasible. On top of that it demands on some occasions a degree of shrewdness to look under the surface and judge whether the arguments being put are for the benefit of the community as a whole or for a particular sectional interest.
>
> Like any rule of law, standards limit freedom in some respects, in the interests of greater freedom or convenience, amenity or cost saving, for the populace at

large. On the other hand, the certainty that standards provide can sometimes imply some rigidity, some resistance to change, or at least inertia against change. This is something that the makers of standards are always on their guard against. It is especially a problem in a technology that is new, or undergoing rapid changes, as for example in the recent history of videocassettes. Then those setting or administering standards have to tread a wary path between, on the one hand, setting standards too early and too inflexibly, thereby inhibiting further development, and on the other hand, waiting too long until a whole range of concepts has proliferated, each a little different from the other. Then either standardisation becomes impossible or a multiplicity of "standards" is legitimised that destroys much of the meaning and advantage of standardisation (Thiele: 1979, pp. 443-447).

In the end, it matters little whether the plethora of standards and specifications around video represent an encouragement of innovation or a failure of regulation: as preservation archivists, we face the task of playing back a dismaying variety of tape formats.

C.1.3 Videotape assessment, prep, cleaning, and hydrolysis treatment: general discussion

C.1.3.1 Introduction

This subsection of IASA-TC 06 concerns physical aspects of videotapes, including inspection of the tape itself, the tape housing (for videocassettes), the way in which tape is wound and packed for storage, as well as aspects of tape condition, notably hydrolysis ("sticky shed") and mould. The section also features advice on the treatment for many of the problems that are identified. Matters pertaining to physical storage are not covered; readers are encouraged to consult *Handling and Storage of Audio and Video Carriers: IASA-TC 05* (IASA-TC: 2014) and various standards.[1]

The descriptions and remedies outlined in this section are *general*, and readers are encouraged to also consult additional, *carrier-specific* advice in many of the succeeding sections: C.3.3 for EIAJ and Sony CV ½-inch Open-reel Videotapes, C.4.5 for 1-inch Helical-Scan Open-Reel Videotapes, C.5.3 for U–Matic ¾-inch Videocassettes, and C.6.3 for ½-inch Analogue Consumer and Semi-professional Videocassettes.

This guideline's scope does not cover the magnetic properties of videotape, i.e., *coercivity*[2] *and remanence*,[3] also referred to as *retentivity*. These aspects of magnetic recordings have an impact on the life expectancy of the recording, and an understanding of the topic is highly relevant to the selection of media when recordings are made. For videotapes, however, that is past history.[4] Information about magnetic properties is also relevant to the storage of videotape collections, a topic addressed in the publication *Handling and Storage of Audio and Video Carriers: IASA-TC 05* (IASA-TC: 2014).

1 Examples include ISO 18923:2000 *Imaging materials - Polyester-base magnetic tape: Storage practices* and ISO 18933:2006 *Imaging Materials - Magnetic Tape: Care and handling practices for extended usage*.
2 Wikipedia, *Coercivity*, https://en.wikipedia.org/wiki/Coercivity, accessed 9 December 2017.
3 Wikipedia, *Remanence*, https://en.wikipedia.org/wiki/Remanence, accessed 9 December 2017.
4 The AMIA listserv has included the discussion of this and related topics. One September 2005 example featured comments on how the recorded magnetic fluctuations data represent changes in the radio frequency that carries the underlying video signal: http://lsv.uky.edu/scripts/wa.exe?A1=ind0509&L=amia-l&F=&S=&P=39812#10 ("Ahh… the clone"), accessed 9 December 2017. Coercivity and retentivity as these relate to videotape are the topic of this March 2008 AMIA listserv exchange: http://lsv.uky.edu/scripts/wa.exe?A1=ind0803&L=amia-l&F=&S=&P=27952#86 ("More then [sic] you may want to know about magnetic tape retentivity"), accessed 9 December 2017.

C.1.3.2 Inspection and physical assessment

The first step in videotape playback is a visual inspection of the carrier itself. A visual assessment of the condition of the carrier and the identification of potential issues that may have an impact on the replay of the tape leads to informed decision-making regarding the most appropriate steps to take. This decision-making will ensure the best chance of successful replay, with the highest possible signal quality and least damage to the carrier itself. The importance of this visual inspection and decision-making step cannot be overstated.

C.1.3.2.1 Case, flange, and enclosure

In the case of videocassettes, a careful inspection of the cassette should be undertaken. Visible signs of mechanical damage such as cracked or broken parts of the case should be assessed to determine if the damage will impede replay, harm the tape, or degrade the quality of the signal. In spite of the cavalier manner in which most videocassettes are treated, the cassette shells are high precision parts of the replay process, and damage will likely have some impact on the quality of replay.

When assessing the cassette for visible signs of damage, careful note should be taken of any rattling from within the cassette that may indicate loose components. Loose parts are doubly problematic in that the missing or misaligned part may reduce the quality of replay, but the loose component may also damage the tape, and the valuable replay machine.

The detection of significant damage or loose components will require that the cassette shell is dismantled and repaired or replaced. This is a precise and potentially risky process and should be approached with great care and caution. See discussion of cassette shell reassembly below.

In the case of open reel video, it is not uncommon for a damaged or deformed flange to impede the pathway of the tape. This can cause edge damage to the tape and have an effect on the quality of replay. It is relatively simple to unscrew metal flanges from the hub, and to repair or replace them. Care must be exercised in ensuring that the tape pack is solid, and the end of the tape is secured to avoid a messy tape spill.

C.1.3.2.2 Tape and pack

A visual inspection of the tape pack should reveal some information that will help determine the next steps to take. *Leafing*, that is a randomly uneven pack, could be a product of the manufacture tape itself, or the effect of the last machine on which the tape was wound. *Blocking*, where "blocks" of the tape are at different levels, may have been caused by mishandling or dropping the tape, or by not completely winding the tape through after its last use. A blocked tape is likely to be deformed at the transition point. In either case, modern PET tapes conform to the shape in which they are stored. When the visual inspection identifies leafing or blocking, an archive should re-wind the tape, multiple times with rest periods between, in order to produce a smooth pack that will support more successful playback.

Curl, the curving of the tape edge to edge, is a product of the manufacture of the tape, often exacerbated by exposure to high humidity or moisture. The treatment for curling is the same as for the other physical deformations mentioned above: rewinding and resting the tape between rewinds until a suitably smooth tape pack is achieved. Modern playback machines may ameliorate minor curling or cupping by putting modest tension on the tape, "stretching" it slightly as it passes over the rotating head. Nonetheless, it is best to re-spool tape, at least once if not a number of times, in preparation for replay.[5]

C.1.3.2.3 Hydrolysis/binder degradation

Before moving to re-spool tape, it is important to check for the artefacts of binder degradation. If the layers of tape are binding together, for instance, then re-spooling before treating the tape may cause damage. The next artefact to look for in a visual inspection is the appearance of a white exudation on the visible surface of the wound tape pack. Though it is often difficult to tell the difference between mould and the artefacts of binder decomposition, the latter appear crystalline in nature when magnified. Care should be taken to avoid exposure to moulds (see below). The difference is especially difficult to see through the window of a cassette.

If there is any suspicion of binder degradation, a careful manual spooling of a small portion of the tape might well reveal some stickiness that would most likely confirm this is the problem. Tapes that suffer from binder degradation may not exhibit higher levels of "stickiness" between the layers of tape, and yet will still cause tape head or tape path to clog and jam if replay is attempted. If binder degradation is confirmed or suspected, heat treatment, or baking, is the most common approach to making the tape playable (see section C.1.3.4, *Baking Tapes: Treating Tape Hydrolysis*).

C.1.3.2.4 Loss of lubricant

Lubricants are included in the formulation of the tape to ensure the critically necessary smooth passage of the tape across the heads. Many tapes used volatile lubricants that were exhausted by multiple plays or evaporated during storage. There is little to indicate loss of lubricant except that the tape will "squeal" as it passes over the heads or fixed guides.

Preservation and video-production specialists have advanced two corrective approaches. The first and most common is heat treatment, often combined with warm replaying (see section C.1.3.4, *Baking tapes: Treating tape hydrolysis*). Some specialists argue that baking is appropriate for loss of lubricant, as the application of heat drives the binders to the surface, however it is difficult to distinguish between the known improvement to hydrolysed tapes and the impact of lubricant loss when attempting to ascertain its effectiveness. The approach should be treated with caution.

The second corrective approach entails the topical application of lubricants to the surface of tapes, thought to alleviate the scrape-flutter that causes the squeal. Silicon oil, graphite, and some other commercially produced mixtures whose precise content is not revealed are the most commonly used. However, there has been little or no published, systematic investigation of the impact of this pragmatic approach. Is playback improved? Do the videotapes or the VTRs retain residue or suffer damage? Until these questions have been investigated, the application of lubricants should be considered experimental and undertaken with extreme caution unless the tapes or VTRs are considered expendable.

5 Some preservation specialists report that bad spots on a videocassette are more likely to be encountered at what are called *thread-unthread* points, i.e., the place at the beginning or end of the tape where the VTR mechanism pulls the tape around the helical scan drum. This topic was discussed on the AMIA listserv in October 2005; see http://lsv.uky.edu/scripts/wa.exe?A1=ind0510&L=amia-l#16 ("Re: Ahh... the clone--What about small-format digital tapes?"), accessed 9 December 2017.

C.1.3.2.5 Mould

As has been previously mentioned, mould can appear as a white deposit on the surface of a tape pack. It can also exhibit other colours and characteristics, and be found on storage boxes, inside cassette cases, or on deposits of dust and other contaminants on the surface of the reel flanges and the tape itself.

Exposure to some moulds can trigger significant health problems, and it is difficult, even to experts in this field, to identify which mould spores are the most likely to cause health issues, and so it is recommended that all instances of mould be treated as a potential health risk. If any doubt exists, seek expert advice.

C.1.3.3 Cleaning

C.1.3.3.1 The cleaning environment

It is sensible to keep a separate cleaning environment for tapes. This reduces the likelihood of contaminating other tapes with mould spores and potentially damaging particulates and is the first step in ensuring that others are not exposed to the risk.

The cleaning area should have open, clear surfaces, which can be easily cleaned and maintained. Conservation professionals recommend that an appropriately rated fan extraction fume hood is the only environment in which a mouldy tape should be treated, and this is certainly worth the investment where there are many tapes which have been affected and in which there are numbers of staff working. At the very least people cleaning mould infected tapes should have available to them a mould safety mask with appropriate filters, disposable gloves, and if deemed necessary, disposable hair and shoe coverings. The area should include a Vacuum cleaner with a High Efficiency Particulate Arrestance (HEPA) filter.[6]

Anyone working with mould-affected tapes should take appropriate action to ensure that they have washed any exposed skin before touching food or beverages.

C.1.3.3.2 Initial manual cleaning

The first step in cleaning a tape is to remove any dust and contaminants from the exterior of the box or other enclosure, and then the exterior surface of the reel or cassette. Using dust cloth, small bristle brush, and the vacuum cleaner mentioned above, the material can be cleared from the outside of the carrier enclosure. Any sticky labels or tabs that impede the movement of the tape or the opening of the cassette enclosures should be removed.

If mould, dust or other exudation is present on the inside of the cassette, or the surface of tape pack, then the cassette case will need to be dismantled and the inside cleaned, or in the case of a reel, it may be necessary to remove the flanges of the reel, taking care to clean both sides of the flange.

C.1.3.3.3 Mould removal (safety warning)

As has already been stated, mould spores may present a health risk, and some spores may, in extreme cases, cause specific problems including respiratory disorders, asthma attacks, infections like sinusitis and pneumonia, allergic reactions, fatigue, and painful inflammation of the joints. Moulds depend on the presence of moisture and a suitable temperature range to flourish. Cold and very dry environments will make moulds much less active, so reduce their ability to colonise a surface. The use of isopropyl alcohol and laboratory grade lint free cloth is effective in removing surface mould.

6 In the United States, HEPA is usually glossed as *High Efficiency Particulate Air* filter.

C.1.3.3.4 Cassette shell disassembly

It may be necessary to disassemble a cassette because the case, or shell, is damaged, and must be replaced, if the inside of the cassette case needs to be cleaned because of excessive presence of particulates, if the inspection revealed loose or rattling parts, or if access to the tape is required to reattach leader tape or splice broken tape. If a cassette shell is to be disassembled it is good practice to stabilise the tape pack using a non-bleeding tape to avoid a catastrophic unravelling. For most cassette shells this can be done before the shell is disassembled with the cassette flap is open.

There are often screws on the underside, which can be removed, then the cassette turned right side up again and the top removed. This must be done with great care, as there are usually a number of moving parts, sometimes with springs attached, which can become dislocated. It may also be necessary to remove labels that bridge the halves, or otherwise slice through them with a blade. If tape itself needs repairing, it is very important to determine which side of the tape has the oxide layer, and only attach splicing tape to the opposite (back) side. Splicing tape on the oxide side of the tape will almost certainly damage the video heads. Leader tapes, which may consist of foil, clear or reflective plastic, depending on the format, must be reattached intact, as they are used to apply the brakes during replay to avoid high-speed running into the spool anchor which can potentially damage both tape and machine.

C.1.3.3.5 Machine cleaning

Though manual cleaning is important in ensuring that no further particulates are spread on the tape, the cleaning of the surface of the tape is undertaken with a cleaning machine. Cleaning machines are routinely used in the replay of videotape, after most of the treatments described above, and before replaying the tape. There are two broad types of cleaning machine, those that only use a cloth (or cloth-like) cleaning surface, and those that additionally use a blade to remove a tiny part of the surface layer.

Burnishing blades within cleaning machines has been a matter for strong debate amongst audiovisual archivists for some time. Sapphire burnishing blades are designed to remove loose particles, debris and some oxide shed from the tape, as well as polishing the tape oxide surface. The process, if successful, is beneficial to the replay of a tape, but there is a risk the blades could damage the tape under the following conditions.

Worn or damaged blades do not clean the tapes, but could instead cause severe damage to the tape surface. If the blade is worn, blades should be replaced. Some machines auto-detect blade condition and provide a warning when one needs to be replaced. Check the blade for damage by regularly running a thin piece of plastic such as a credit card or similar along the sharp edge of the blade, if the card does not run silently and smoothly this is an indication that there are problems with the edge of the blade (RTI: 1994). Worn or damaged blades must be sharpened or replaced, a task generally undertaken by an appropriately experienced machinist.

If the machine has one or more burnishing blades, clean it before every tape clean, so that excess oxide built up on the blade does not scratch the surface of the tape. Be careful when cleaning the burnishing blade as they are very sharp.

If a tape has known physical damage such as splices or damaged or twisted tape, do not attempt to clean with sapphire blades, as the tape could be cut. Some cleaning machines have the ability to move the blade out of the tape path before cleaning.

Special care must be taken when threading tape past the sharp burnishing posts.

Even through there are risks involved with using blades, they can enable better quality playback in some cases. It is up to the institution or technician to decide what the most appropriate actions for the collection or item are. Some archives have a policy not to include blades in their cleaning machines, while others use them routinely. In general, the benefits of a single cleaning pass on tapes in reasonable physical condition exceed the detrimental aspects of removing some of the surface; multiple cleanings will inevitably and eventually damage the tape.

If using a cleaning machine, it is advisable to run the machines with the lid off so as the tape handling in the transport can be observed, and the machine stopped in the event of damage. However, as machines use optic sensors for detecting physical damage and the start or end of tape, high levels of light should be avoided as the light could disrupt the sensors and cause the machine to malfunction. For very dirty tapes, Pellon tissue roller advancement should be checked (or manually advanced more frequently in more basic machines) otherwise excess oxide build up could scratch the videotape.

The risk of damage in a cleaning machine is low to medium if the above guidelines are adhered to, however the consequence of damage could be very significant, and for these reasons, a cleaning machine should never be left to run unattended.

If the cleaning machine has an erase feature, it should be disabled to avoid accidental damage.

Cleaning machines were originally designed to recycle and reuse old tapes. Systems like those manufactured by Research Technology International (RTI) and Bow Industries use optical and opto-magnetic detection systems to identify damage or potential tape failure. This feature is of little use for archival assessment, as it identifies a tapes value for reuse, rather than the quality of its replay characteristics.[7]

Machines developed specifically for archival purposes have implemented more advanced surface scanning capability, but even so the results still require interpretation. As we move towards loss of access to formats and loss of carriers, the best place to assess the quality of the video carrier is at the point of replay and digitisation, though the identification of damage may help in determining the correct tools and processes to use.

C.1.3.4 Baking tapes: treating tape hydrolysis

C.1.3.4.1 Background

In almost all manufactured videotapes the substrate, or carrier, is a form of plastic, most likely *polyethylene terephthalate* (PET) or more latterly *polyethylene naphthalate* (PEN). PET is the most common form. It is very stable and is relatively strong even when made very thin. PEN is found primarily in data and later digital videotapes and exhibits even better stability characteristics. The substrate is rarely the cause when a tape is difficult to replay.

The information recorded on a videotape is encoded in the magnetic particles distributed across the surface of the substrate and held in place by the binder, which is frequently a form of *polyester urethane* (PU), incorporating lubricants and plasticisers using a variety of proprietary and often secret ingredients which make up the formulation of the binder.[8] When a tape becomes sticky or sheds, it is the degradation of the binder that is the cause.

7 Methods and devices for automated, pre-transfer detection of videotape flaws received vigorous discussion on the AMIA listserv in April and May 2006: http://lsv.uky.edu/scripts/wa.exe?A1=ind0604&L=amia-l#146 ("RTI cleaning machine defect detection") and http://lsv.uky.edu/scripts/wa.exe?A1=ind0605&L=amia-l#162 ("RTI cleaning machine defect detection"), both accessed 9 December 2017.

8 This is not the case with Metal Evaporative (ME) tapes. Baking or cleaning ME tapes may well cause damage.

Researchers and manufacturers became aware of the problem of binder degradation in the late 1970s and a flurry of research publications followed, and continues until the present. The earliest papers identified hydrolysis as the mechanism of breakdown.[9] Hydrolysis is a reversible reaction, and the application of high temperatures and low humidity was recommended as a means of undoing the process. However, further research has indicated that while hydrolysis remains a key component of the breakdown mechanism, there were a number of other factors that interacted with the oxidation and decay of the polymers such that it became difficult to model the reaction as the simple process it was first thought to be (Bradley: 1995).

Binder degradation was first revealed, and most commonly occurs, in tapes of American and Japanese manufacture (e.g., Ampex, Scotch 3M, Sony) from the late 1970s to the mid 1990s. Though this broad category of tapes is the one that most commonly exhibits the problem, virtually every tape manufacturer of tapes with a PU binder has encountered the problem at some point. Tapes of European manufacture, such as BASF and AGFA, present their own type of binder degradation characteristics while still being a form of hydrolysis. The question remains as to whether this sort of binder degradation is the eventual fate of all PU tapes, or whether it was a failure of manufacture within a bounded period of manufacture (Hess: 2008).

In a series of interviews with tape manufacturing experts in Germany, Dietrich Schüller found evidence that the binder recipe and the manufacturing process resulted in variation between and within batches of tapes that lead to increased likelihood of sticky tape (Schüller: 2014). This argument suggests that hydrolytic breakdown of the binder is not the unavoidable end point of all tapes with a polyester binder, but only those whose binder mixture and distribution predisposes them to failure.

C.1.3.4.2 Heat treatment of sticky-shed videotapes

Heat treatment, followed by cleaning, is the IASA-TC 06 recommended process to restore unplayable, sticky, shedding tapes, and the method is described below.[10] Heat treatment is effective when the degradation reactions are hydrolytic in nature (Lindner: 1996).

All heat treatment should be undertaken in a laboratory-standard thermal convection oven, designed to achieve and maintain the desired set point temperature in a very stable manner. The accuracy of the set point is critical, as indicated below. Falling short of that temperature may result in the failure to make the tape playable and exceeding it can cause damage. Laboratory ovens specify their accuracy at ±1 degrees C or less. In contrast, as every cook knows, domestic ovens have an uneven distribution of heat resulting in hot and cool spots, and they tend to cycle between high and low set points, typically ±5 degrees C.

Though polyester tapes are quite stable, they have a small thermal expansion coefficient which can produce physical deformation of the tape when heated. The uneven temperatures and set-point cycling in a domestic oven applied to the geometry of a wound tape increases the likelihood of deformation. Although re-spooling the tape tends to disperse deformation, the use of a laboratory-standard oven is the best way to prepare sticky tape for digitising and avoid physical issues.

9 See the following, referenced in the IASA-TC 06 bibliography: Cuddihy, E.F.: 1980, pp. 126-135; Bertram and Cuddihy: 1982; Brown, Lowry, and Smith: 1982; Brown, Lowry, and Smith: 1983; Brown, Lowry, and Smith: 1984; and Smith, Brown, and Lowry: 1984.

10 In recent years, some magnetic recording specialists have analyzed the sticky shed phenomenon and have developed alternate findings as well as treatments that do not entail baking. One such example entails the removal of the tape's back-coating binder, a process developed by Charles A. Richardson and marketed by Rezerex, Inc.; see http://rezerex.com/, accessed 9 December 2017.

The recommended minimum temperature for heat-treating a tape is 50 degrees C. This is the temperature at which the PU binders undergo a chemical change and become playable. The treatment is also accompanied by a change in surface smoothness, viewable under very high magnification. However, the variability in the makeup of the binders between brands and batches of tape mean that some tapes may need to be treated at a slightly higher temperature than 50 degrees C to achieve the same result. The recommended maximum limit is set at 55 degrees C because PET, the substrate or "film" which carries the binder layer, may soften and possibly deform as it passes through the glass transition temperature, which can be as low a temperature as the mid-60s.[11] So keeping the baking temperature well below that transition temperature is prudent.

The period for which a tape should be treated with heat varies with the size of the tape, the thickness of the tape, and the length of the spool. Generally, the period is for is 8–12 hours, though for tapes which do not satisfactorily play after treatment, this period may be repeated. We recommend that large reels of 2-inch and 1-inch tape be treated for two or more periods of 8–12 hours, and re-spooled in between.

Some practitioners have had success with playing the tapes while still warm and claim that this improves the quality of replay. Tape loses temperature quickly when spooled. On the other hand, winding the tapes before replay has the effect of reducing the level of print through and helps to redistribute tensions in the tape.

Tapes should be placed in a cool oven and brought up to temperature rather than placed in a hot oven, which exposes the tapes to thermal shock and uneven dimensional change that exacerbates mechanical tensions.

Some practitioners recommend treating tapes at very low humidity at room temperature for extended periods, often for weeks. There are some successes associated with this approach, though it is not always effective, and cannot reach the clear transition that higher temperatures achieve.

Like all technical advice, it is strongly recommended that it be applied carefully and conservatively, and always within the limits of the individual's technical abilities.

11 Glass transition temperature of polyester commences somewhere approaching 67 degrees C. The Vicat softening temperature is a measured point at which a substance reaches a particular measured level of softness and is most commonly used as an evaluation for substances that do not have a precisely defined melting temperature. For polyester, the Vicat A is 67 degrees C.

C.2 QUADRUPLEX 2-INCH VIDEOTAPES

C.2.1 Introduction

C.2.1.1 Format history and featured technology

The 2-inch open reel videotape format called quadruplex or *quad* was introduced in 1956 at a broadcaster's convention in Chicago and was the first successful broadcast videotape format. Quad was a breakthrough in video recording technology. It enabled recording and instantaneous playback of moving images from a video source. Prior to quad, the only option was motion picture film. Film, however, required time and chemicals to be developed and played back. With quad it was convenient to time-shift a program—for example, showing the 6 pm news again at 10 pm—and to pre-record a program for later broadcast. This made television programming more convenient and allowed for the recording of multiple takes that could be assemble-edited together.

The performer Bing Crosby played a role in Ampex's development of the technology. Crosby's distaste for live broadcast led him to invest in technologies that would allow pre-recording of broadcast content.[12]

Quad was an enormous technological leap. Many technologies were developed and brought together to make it possible. Not only recording on tape, but also the use of spinning heads, the introduction of time-based correction, dropout compensation and, in time, the development of interoperability of tapes that permitted electronic editing. The Wikipedia article "Magnetic tape," reports that a team at Ampex led by Charles Ginsburg "made the breakthrough of using a spinning recording head and normal tape speeds to achieve a very high head-to-tape speed that could record and reproduce the high bandwidth signals of video. The Ampex system . . . used 2-inch-wide (51 mm) tape, mounted on reels like audio tape, which wrote the signal in what is now called transverse scan."[13] Various patents were assigned to protect aspects of the technology, but quad was never brought under the auspices of a standards body like SMPTE.[14]

C.2.1.2 The use of frequency modulation

One important technological breakthrough that facilitated video recording was the use of frequency modulation (FM) to record the signal onto the tape. Compared to audio, video requires the recording of much higher frequencies. If the video is used to frequency modulate a carrier signal (with a "frequency of its own"), the resulting frequencies recorded on the tape are even higher. This fact makes the use of any type of modulation seem counterintuitive; but the use of FM solved two big problems. First, it reduced the number of octaves the recorded signal spanned. Second, FM made the reproduced image relatively impervious to variations in the amplitude of the reproduced signal, unwanted variations that might occur as a signal passed through the recording process.

12 Numerous articles provide accounts of Bing Crosby's preference for pre-recording his radio and (later) television broadcasts and report his financial support to Ampex as they developed what became the first videotape recorder in the late 1940s. See for example Robert R. Phillips's "First-Hand: Bing Crosby and the Recording Revolution" (Phillips: n.d.). Readers interested in the pre- and early development of videotape technology are encouraged to pursue the topics *Bing Crosby Enterprises (BCE)* and the *BBC VERA* project.

13 Wikipedia, *Magnetic tape*, https://en.wikipedia.org/wiki/Magnetic_tape, accessed 13 April 2018.

14 The most important quad patent is U.S. Patent 2,866,012, "Magnetic Tape Recording and Reproducing System," Ampex Corporation, filed May 1955, issued December 1958; online at http://pdfpiw.uspto.gov/.piw?Docid=02866012, accessed 15 April 2018. Readers should note that IASA-TC 06 uses the word *standard* in a narrow sense, for specifications set by standards-setting bodies like the Society of Motion Picture and Television Engineers (SMPTE) and the International Standards Organization (ISO). Quad technology is *standardized* in a looser sense, in effect, a de facto "industry" standard.

In the beginning, the FM carrier was only slightly above the highest frequencies in the video.[15] This worked reasonably well for black and white where there was only a limited amount of high frequency information in the video to begin with. However, NTSC colour—a standard first adopted in 1953—carried the colour information in a high frequency subcarrier. This subcarrier will *beat* with the FM carrier causing an additional signal to be generated at the difference frequency, which produces a bothersome *moiré* pattern.[16] To reduce the moiré effect, the carrier deviation had to be reduced, keeping the FM frequencies to the high end of what it was possible to record. While this reduces the moiré, it also reduces the signal to noise ratio of the reproduced video.

C.2.1.3 Introduction to recording specifications or modes

The two recording specifications—sometimes called *modes*—described in the preceding section became known as *low-band monochrome* and *low-band colour*. (These and other specifications or modes receive additional discussion in section C.2.5.2.) The term *low-band* came into use because, over time, it became possible to record and reproduce higher frequencies. This led to a third specification (mode) known as *high-band*, in which the FM carrier frequencies are substantially above the frequency of the colour subcarrier, allowing greater frequency deviation of the FM, thus improving signal to noise while keeping moiré levels low.

With the introduction of high-band, some specialists stated that even a trained eye might not be able to tell tape playback from live. This claim had some credibility at the time, considering the image quality produced by the cameras prevalent in the mid-1960s.

Later, toward the end of the life of the format, it became possible to record even higher frequencies. This resulted in the fourth specification or mode, *super-high-band*. These higher carrier frequencies allowed a *pilot signal* (or *pilot carrier*) to be added to the video. The pilot is highly useful in the time base correction process discussed in section C.2.11.3. Incidentally, there was also a fifth mode, referred to as *slow-* or *half-speed* (see section C.2.5.2).

C.2.1.4 Initial cost of acquisition

The cost of quad machines was extremely high. The 1956 price of the first quad machine, the VR-1000, was US$50,000, the equivalent of US$450,000 in 2018 terms, or many times the cost of 2018's current generation of high definition digital television (HDTV) recorders.[17] Purchasing of quad was a major commitment, especially since most broadcast stations would have at least two machines, the primary and a backup. Early market research estimated the US market for a videotape recorder to be 20 machines, more or less picturing two machines at each of the three major network broadcast centres in New York, Los Angeles, and Chicago. However, Ampex took orders for 100 VR-1000s at the 1956 NARTB Convention[18] where quad was introduced to the world.

15 Each 1MHz of bandwidth translates to approximately 80 lines of resolution in analogue video.

16 The term *beat* refers to an interference pattern between two slightly different frequencies. In the case of sound, the beat may be heard as a periodic variation in volume whose rate is the difference of the two frequencies. For picture, the *beat frequency* appears in the picture as wavy lines, i.e., the *moiré* pattern mentioned above.

17 At this writing, for example, the Sony SRW-5800/2 recorder for the HDCAM-SR format, retails for between US$70,000 and $75,000.

18 National Association of Radio and Television Broadcasters, later renamed NAB, National Association of Broadcasters.

Figure 1. Ampex VR-1000 at Museum of Broadcast Technology in Woonsocket, Rhode Island.

C.2.2 Extent of 2-inch quadruplex holdings and urgency of preservation

Due to the very high cost of machines and blank tape, nearly all holdings of quad will carry programs produced in high end, professional contexts. The large, heavy tapes can be challenging to store. Since the 1960s, many collections have been discarded to save space, and to avoid the cost of keeping the large and obsolescent quad VTRs operating.[19] Such discarding was especially prevalent following earlier rounds of duplicating quad tapes to other formats including 1-inch Type C, BetacamSP, and Digital Betacam. Nevertheless, there are extensive holdings at the Library of Congress and in selected broadcast archives, as well as smaller collections, ranging from a handful to a few hundred tapes, in many archives.

The raw tape stock was very expensive. In 1975, for the price of a few reels of quad tape, about US$700, you could purchase a good used automobile.[20] In the heyday of quad production, it was very common for the tapes to be erased and reused.

Quad tape stock suffers from all the problems familiar to anyone working with analogue audiovisual playback. These include catastrophic oxide failure, and sticky shed syndrome. See section C.2.4.3 for more information.

19 VTR is an abbreviation for video tape recorder. Although the *R* stands for recorder, in the context of this discussion, VTRs are employed to play back a recording.

20 Thanks to James Snyder, Library of Congress, for this observation. In 1975, new Fords and Chevrolets retailed for about US$3,500 to 5,000.

Informal conversations among specialists tend to include the anecdotal estimate that fewer than 100–200 functioning machines still exist worldwide. Whatever the true number, it is very small in comparison to the hundreds of thousands of tapes that remain.

Quadruplex video is *highly* endangered and should be prioritized for digitisation if the content is important to the collection.

Quad was not the only 2-inch tape format. Government, aerospace, early education television (both broadcast and internal university or school productions), or corporate video archives may hold or encounter non-quad 2-inch tapes that could be mistaken for quad tapes. Here are some examples:

- 2-inch audio tape (may be identified via labelling, or by the presence of the track sheets used when mixing a multitrack recording)
- 2-inch reels with small spindles (probably Sony PV-family helical-scan tapes)
- 2-inch reels with two video channels (octuplex), developed for the military FR-family data recordings
- The Ampex VR-660 machine, a 2-inch helical scan machine popular in industrial applications in the 1960s.[21]
- The IVC-9000 machine, a 2-inch helical, super-high-band, high quality machine from the mid-1970s used in sophisticated production.

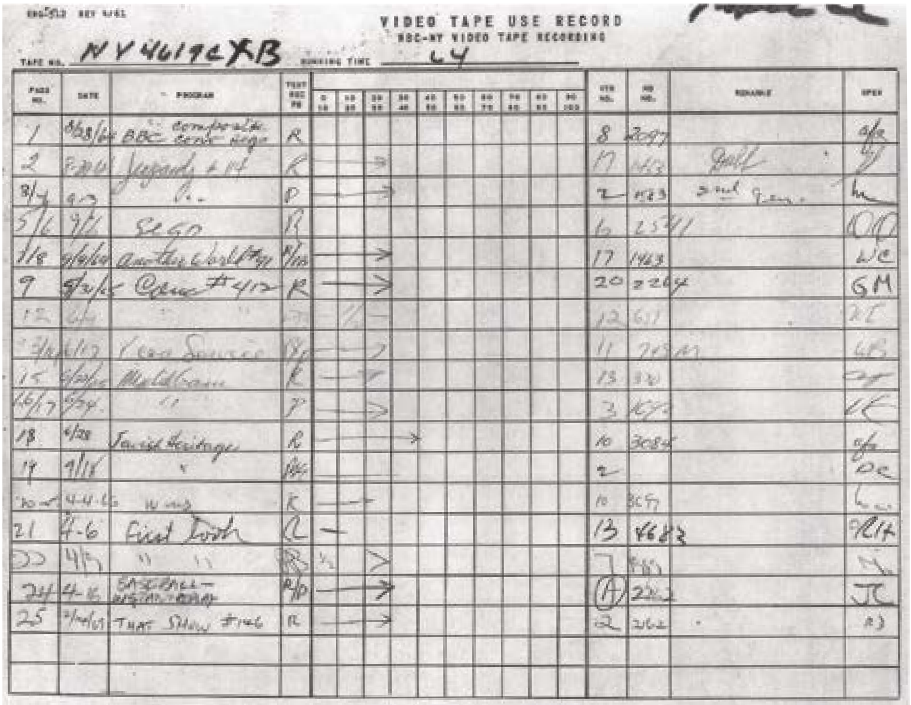
C.2.3 Selection of best copy

Due to the high cost of blank tape and the ongoing cost for machine operation and periodic replacement, as well as for engineering support, the production of a quad tape was not a casual action. Indeed, after the content of a tape had been initially broadcast, the tape was frequently reused for a follow-on program. It is common to find cards or slips of paper inside a quad-tape storage box that list the number of times this tape had been reused.[22] An archivist may also find a list of the contents that had previously been recorded on a tape, the original broadcaster's way of reporting, "yes, we did record that, and then we reused the tape."[23]

21 An author to this section remembers, VR-660 was the most popular model of this machine, however, I believe VR-560, 660, 1550, & 1560 were in this general format. There were a number of variations. Most engineers know this format at VR-660.

22 Broadcast veterans sometimes pass along the story that Edgar Rosenberg, the husband of television star Joan Rivers, was so cheap he would only record *The Late Show with Joan Rivers* on a reel of tape that had been reused so many times that no one else would use it. Since such a reel was past its prime, the Rivers program tapes were not reused yet again and, for this reason, it is said, those programs survive.

23 One of the authors of this section was digitizing a collection that included a reel that had been reused about ten times. The paper list accompanying this reel of tape provided the titles "Gemini splashdown" and "Nixon/Kennedy Debate" as prior uses; the content that remained on the tape from its final recording was video of a sports league championship.



VIDEO TAPE USE RECORD
NBC-NY VIDEO TAPE RECORDING

TAPE NO. NY 4619C XB RUNNING TIME 64

Figure 2. Video Tape Use Record sheet from the NBC network New York City operation, with recording dates from 1964–1969.

Although quad copies of quad originals can be quite high quality, it is possible that these copies include visual or aural defects that represent "baking-in" the kinds of undesirable artefacts that often occur when playing back quadruplex tapes, often due to poor head equalisation, scalloping error, and noisy or clogged heads. These topics are discussed in the sections that follow, especially C.2.7.

C.2.4 Cleaning and carrier restoration

C.2.4.1 Physical inspection of the housing

It is important to inspect the reel flanges to be sure they are absolutely flat. Signs of shedding and contamination may also be found in the plastic or fibreboard boxes that house the reels.

Late in the quad era, 3M/Scotch introduced a reel that had a foam lining inside the upper flange. It was used throughout the 400 series tapes. This design was also used for 1-inch open-reel videotapes. The adhesive that holds the foam in place may change properties, seep through the foam, and deposit a very high-tact residue on the tape. While it is possible to remove the residue chemically, it nonetheless represents a high risk during playback. Playback of a tape with this condition is very likely to damage the heads, and/or the machine. If you have a tape with a foam flange, always remove the flange completely to examine the tape for even the slightest residue.

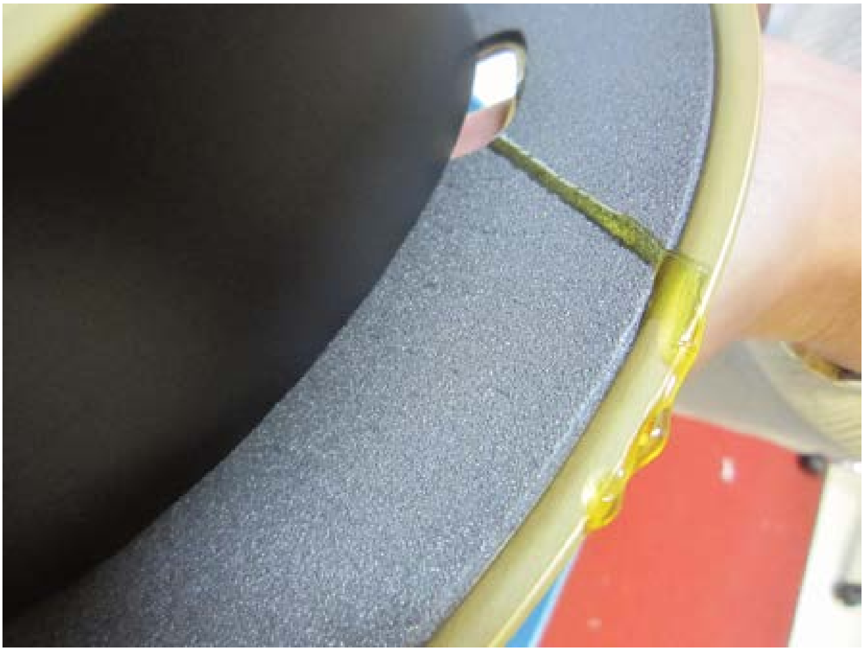


Figure 3. Quad reel showing foam flange and failing glue.

Figure 4. Severe case of foam flange glue failure.

The authors are not aware of any scientific studies or documentation that provide guidance on the treatment of this condition. Vendors who perform this work tend to be very quiet about the agents they are using, both to protect their trade secrets and for fear someone will object to the process. Anecdotal discussions with practitioners identify a range of agents, including acetone and perchloroethylene, both of which are toxic to humans, even carcinogenic, and that require hazmat and special handling. Any such treatment should be considered compromising to the long-term life of the tape. Once treated and the residue removed, the tapes should be digitized promptly before they deteriorate further.

If the tape was not properly wound onto the reel, e.g., if it was stored improperly, or if transported with high vibration, the tape pack can become loose. This is very dangerous when the tape is played back, risking damage to the VTR. Playback of tapes in these states will likely cause expensive repairs and are potentially dangerous to the operator. Poorly packed reels might be handled best on older machines that employ less sophisticated reel motor control.

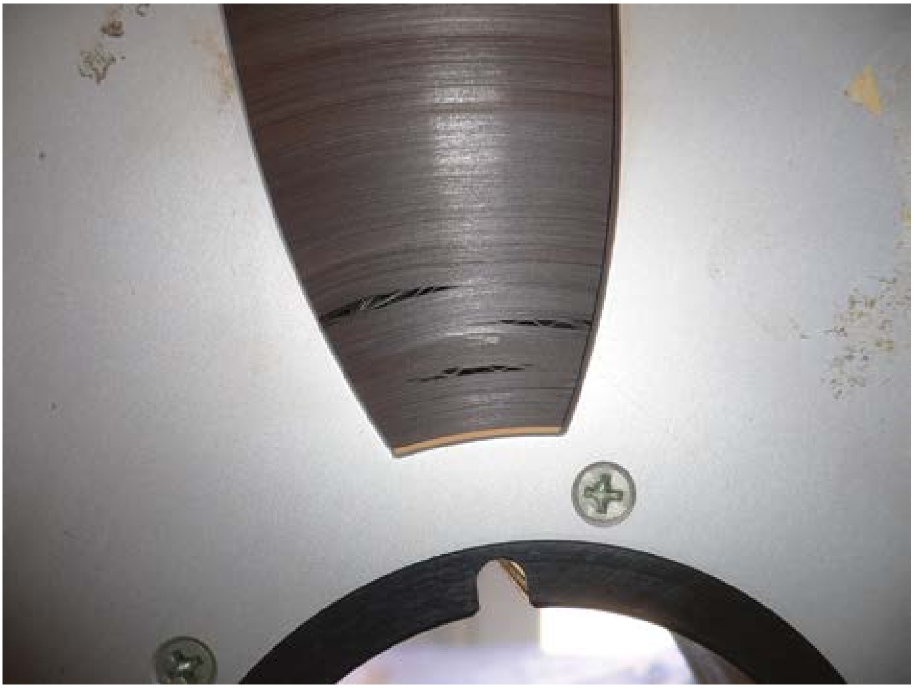


Figure 5. Examples of poor tape pack and its effects on the tape. The first image depicts an example of wrinkled red oxide tape; in addition to the wrinkling, the oxide has come off the bottom edge of the tape.

C.2.4.2 Tape formulation

Early forms of 2-inch physical media include examples with a red oxide coating shown in the first image in Figure 5. Casual observers may be deceived by this tape's resemblance to acetate audiotape. (In fact, the earliest quad tape media was audiotape, albeit with a polyester base.[24]) Later forms of 2-inch quad videotape bring us to the most advanced back-coated formulations, shown in the second image in Figure 5.

Every tape should be evaluated individually. Nonetheless, there are some useful heuristics. Specialists in the field offer the following general assessment:

- Consistently problematic: Ampex "rainbow" tapes, Memorex, RCA brand, 3M/Scotch 400-420 (foam flange)

- Generally, trouble free: Fuji brand tapes

C.2.4.3 Cleaning

Archives should plan to clean all quadruplex tapes before playback. Nearly all tapes display some amount of oxide shedding that may clog tape heads and impair playback. Some tape stocks shed very badly. While simultaneously addressing shedding, tape cleaning also allows for a preliminary inspection of the media to check for splices, folds, creases, uneven, or deformed tape, and to look for other physical degradation that will impair playback. Given the very high cost of operating quad machines, not the least is the cost of heads,[25] the ability to assess tape condition prior to playback is very important.

Care must be taken to not imbed a scratch along the length of the tape. Even loose oxide caught in a stationary guide or audio head or erase head can cause a "magnetic" scratch aligned with the tape's main direction of movement. This is why later machines put some heads on the backside of the tape. A scratch, magnetic or physical, will cause a diagonal pattern of dots to appear in the picture that cannot be removed.

Tape transports should be cleaned before each tape is played. Isopropyl alcohol (99 percent) and a Pelon or Tyvek tech wipe are commonly used. If the tape is shedding, or if the residue is difficult to remove, a strong agent may be needed. Acetone, perchloroethylene, and carbon tetrachloride are good for this purpose. However, only highly experienced technicians should use these highly toxic agents, in a well-ventilated area.

24 Valuable descriptions of many types of physical media are provided by the *Preservation Self-Assessment Program* website at the University of Illinois (University of Illinois at Urbana-Champaign, n.d.). 2-inch videotape and related containers are described on this page: https://psap.library.illinois.edu/collection-id-guide/videotape - video2inOR.

25 One of the authors of this section reports that, as of January 2018, a typical cost for a replacement head is US$5,200. These heads are guaranteed to last 200 hours but are unlikely to last 500 hours. This compares to the 1,500 or 2,500 hours working life common in other audio and video tape formats, or even 10,000 hours for audiocassette heads.

Figure 6. Tape cleaning devices for 2-inch magnetic tape. In the rack below the operational part of the cleaning device are *evaluators* that prepare and print out reports on the cleaning process, offering an assessment of the tape's condition.

C.2.4.4 Baking tapes

The baking of 2-inch quad tape to mitigate the effects of hydrolysis (sticky shed syndrome) follows the same processes discussed for other formats in IASA-TC 06; see especially section C.1.3.4. Although one might expect the process for 2-inch to take longer than the process for, say, 1-inch, this is not necessarily the case. The length of baking time depends on such factors as tape condition, prior storage conditions, current atmospheric conditions, tape formulation, and manufacturing, any one of which may influence baking duration as much or more than the tape width.

C.2.4.5 Other factors, especially humidity

In addition to the factors discussed above, environmental conditions also have a significant impact on the playback of quadruplex videotapes. High humidity (45 percent relative humidity and greater) will impede playback and cause higher wear on the heads. Ideally the rooms where tapes are stored and played will have low humidity. If humidity control is not available, postpone quad playback until the drier months of the year.

C.2.5 Replay equipment (playback VTRs)

C.2.5.1 Background

There were two main manufacturers of 2-inch quadruplex videotape machines: Ampex, the inventor of the format, and RCA. The Wikipedia article "Quadruplex videotape" reports that Ampex introduced more than a dozen models (including variants on earlier models) between 1956 and 1975;[26] see figure 7 for representative examples. The same article lists twenty RCA models (including variants on earlier models) between 1957 and 1972; see figure 8 for representative examples.

Figure 7. Representative Ampex quadruplex recorders at the Museum of Broadcast Technology in Woonsocket, Rhode Island.

26 Wikipedia, *Quadruplex videotape*, https://en.wikipedia.org/wiki/Quadruplex_videotape, accessed 13 April 2018.

Figure 8. Representative RCA quadruplex recorders at the Museum of Broadcast Technology in Woonsocket, Rhode Island.

In addition to the American companies Ampex and RCA, quad machines were manufactured in Europe, although at a reduced scale. The German firm Bosch produced a small number of recorders for markets in Western Europe and in the East, especially for the Soviet Union. Specialist engineers working to preserve 2-inch tapes often regard Bosch recorders as "a different beast" and do not recommend them except in rare and special cases. Bosch recorders were not marketed in the United States, although a handful may have found their way across the Atlantic. The Wikipedia article "Quadruplex videotape" lists three Bosch models, with the latest one introduced in 1972.[27]

Soviet manufacturers used reverse engineering to produce quad VTRs that copied Ampex designs and technology. The Wikipedia article "Quadruplex videotape" list seven Soviet models from two manufacturers, with introductions beginning in 1964.[28]

27 Ibid.
28 Ibid.

Figure 9. Bosch quadruplex recorder, photographed in Russia.

Quad recorders built before 1962 had tube electronics. Very few of these earliest machines are still running. Over nearly 25 years of new-model introductions, the technology improved significantly. Later machines are more reliable and produce better picture. The last 2-inch videotape recorders were made in 1982, instances of the Ampex AVR-2 and the RCA TR-600C.

It was very common for each model of quad to improve throughout its production time. Many changes or modifications were made to machines during the period when a given model was being manufactured, often from one recorder to the next, "adjacent on the assembly line," as it were. It is therefore very common for the maintenance manuals not to match the specific serial number being serviced. Archivists are encouraged to consult with others who own the same or similar machines to compare versions of the operator or maintenance manuals. Furthermore, some of the design changes make parts, such as circuit boards, incompatible between versions of the "same" machines. Swapping boards, an otherwise routine troubleshooting technique, could cause damage.

C.2.5.2 Modes of operation, additional information

This section continues the discussion of *recording specifications*, also referred to as *modes*, from section C.2.1.3 above. There were four main variations of 2-inch quad and a fifth mode that was less successful and less widely employed:

- Low-band monochrome, the first variety of quad introduced by Ampex in 1956
- Low-band colour
- High-band, generally used for colour, which used a wider bandwidth for recording video to the tape, resulting in higher-resolution video from the VTR
- Super-high-band, which used a *pilot signal* (also called *pilot carrier* or *pilot tone*) for better time base stability, and required higher coercivity tape
- Slow- or half-speed, greater recording time per reel at the cost of image quality

Most quad recordings are made at 15 inches per second (ips). Some machines were capable of slow speed record/play at 7.5 ips, the fifth mode. To maintain picture quality, 7.5 ips recordings require heads with a gap half the size of regular heads (10 mil for 15 ips; 5–6 mil for 7.5 ips). Playing 7.5 ips tapes with 15 ips heads yields poor results, especially an increase is picture noise.

Regarding the five specifications, it is the case that most recorders will be able to reproduce only one or two of the modes. This is especially true when non-NTSC (roughly speaking "European") broadcast standards are encountered. To play back a PAL tape, you need a PAL machine. The most prominent exception to this is the Ampex AVR-1. This recorder can play all variants and video standards except super-high-band. The RCA model TR-61 was switchable between NTSC and PAL for high-band colour. The RCA TR22B had a multi-standard module that could switch between 405-, 525-, 625-, and 819-line standards. An experienced quad technician may be able to modify a machine to change or switch between standards.

The Ampex AVR-1 included multi-standard operation as a standard feature. Many models of quad machine offered switchable video standards as an extra cost option. Most machines, except the very earliest, offered operation at half speed; but, in all cases, required changing out the video head panel to one with half width heads; the panel being the extra cost option.

C.2.6 Equipment maintenance for quadruplex VTRs

Their large size, structural design, and aspects of the electronics make quad VTRs relatively easy to service. It is still comparatively easy to do component-level repair. However, many components have become difficult to procure, especially very large value capacitors, large transformers for power supplies, and highly specialized components unique to the format. Furthermore, many components used throughout the machines contain materials that are now known to be hazardous, such as PCB. This prohibits the manufacture of some identical replacement parts. Meanwhile, at this writing (January 2018) there is a single company, with a single employee, rebuilding quad head assemblies. The sole employee is nearly 80 years old.

In general, there are few experienced quad technicians, and most are elderly. However, more than any other videotape format, there are also hardcore quad enthusiasts and a few vendors have running machines. Within this small, close-knit community information is shared freely. If you need information about quad, seek out these people. They will help you find parts, technicians, manuals, where unusual formats are, etc. Nonetheless, if you seek to get a non-working machine into operating condition, expect the undertaking to require significant resources of time and money.

All quad machines require dried compressed air. At a minimum all quad machines use the air for air bearings behind the head wheel, and, when converted to a vacuum, the vacuum is used to hold the tapes in the female guide that positions the tape for safe reading by the spinning heads (see also section C.2.7.2.1). Some Ampex machines also use the compressed air for air bearings, vacuum columns for tape tension, and a pinch-roller-less capstan used the vacuum where the vacuum holds the tape against the capstan.

C.2.7 Equipment alignment for quadruplex VTRs

C.2.7.1 Calibration tapes and test media

No company has produced calibration tapes or test media for quad for several decades. Any alignment tapes you may happen upon will certainly be old and deteriorated. The best one can hope for is to have a "known good" tape made on a machine in good working order to serve as a baseline. See also section D.1.3.1.4.4 (VTR alignment and calibration using pre-recorded tapes, especially D.1.3.1.4.4.4 (House-made or third-party VTR alignment and calibration tape).

House-made or third-party VTR alignment and calibration tapes are far from true calibration tapes but are certainly better than nothing. In the case of 2-inch quad media, the production of such a tape is made more challenging because there is very little incentive for anyone to keep a 2-inch machine capable of recording. The focus of all effort today is on playback in order to support the preservation of the at-risk videotapes held by the world's archives.

C.2.7.2 Correction and adjustment for satisfactory replay

C.2.7.2.1 Tracking

As described in the Wikipedia article *Quadruplex videotape*, the quad VTR employs "four magnetic record/reproduce heads mounted on a headwheel spinning transversely (width-wise) across the tape . . . . This method is called *quadrature scanning*, as opposed to the *helical scan* transport used by later videotape formats."[29]

This type of recording is called *segmented*: each head pass across the tape lays down part of a frame. IVC 9000 2-inch helical scan recording, mentioned previously in section C.2.2, is another important format that employs segmented recording, as is 1-inch helical scan, type B (described in section C.4.3). In the case of quad, the head wheel carries four identical heads, and spins at 14,400 rpm for NTSC (960 recorded stripes per second), and 15,000 rpm for PAL (for 1,000 stripes per second). Each head is responsible for 8 bands of 16.41 lines (sometimes 16 and sometimes 17 as there is extra information recorded at each end of each track) with two of those bands occurring during the vertical interval and not visible in the picture. For the reconstructed video frame to be smooth from top to bottom, the output of the heads must be aligned electronically and mechanically.

29 Ibid.

Figure 10. One of four heads on the headwheel.

The quad format's unique four-head system and other VTR-operations features mean that quad requires more adjustments than other formats, especially when compared to formats like those described in later sections of this guide in which a helical scan records a whole frame of video in a single drum rotation.

The alignment of quad VTRs relies upon the careful use of vectorscopes and waveform monitors, just as for the other formats discussed elsewhere in IASA-TC 06. Aspects of this topic are discussed in sections D.1.3.1.4, D.1.3.1.5.

Figure 11. Knobs that control the settings on an Ampex quad VTR. Differential gain (DG) and equalisation settings are critical controls to minimize or prevent "banding" in the picture, as shown in figure 12.

Figure 12. Video monitor showing bands that result from improper equalisation between the heads.

Equalisation compensates for electrical and mechanical difference between the four heads so that each head reproduces all frequencies the same way, resulting in a superior picture. It is important that the frequency responses of the four video heads match exactly. If the frequency responses do not match, the color reproduced by the four individual heads will not match, and individual head bands will show up in the picture with different colour intensities, as shown in figure 12. Different machine designs provide different degrees to which the frequency response may be adjusted and thus the color reproductions matched.

With the exception of the very first model of Ampex VR-1000, all quad machines provide an equalization adjustment for each of the four video heads. This is a general high frequency response adjustment for each head. It will affect the overall color saturation of the picture band produced by that head. Both Ampex and RCA offered accessories to make this adjustment automatically. The Ampex system is called Autochroma. In this system, the Autochroma correction voltage replaces the four equalization adjustments and those controls become inactive. RCA called this system Chroma Amplitude Correction, or CAC. This correction is made down -stream of the four individual equalization controls. Thus, in the RCA implementation, the four equalization controls can be used to "center up" the CAC error voltage to allow for the best possible correction.

Many machines have additional controls that effect the highest of high frequencies produced by the individual heads. There may be one or two controls for each of the four heads depending on the circuit design.

If there is a single additional control it will be called differential gain, or DG. Differential gain refers to the saturation of colors in bright areas of the picture versus the saturation of colors in the dark areas of the picture. To make this adjustment using a waveform monitor, one would set the monitor to display two fields of video and while reproducing color bars, adjust the DG controls for the top of the waveform to be even. DG controls and equalization controls do interact. Again, using the waveform monitor set to two field mode and playing back color bars, one would adjust DG to make the top of the waveform equal and equalization to make the bottom of the waveform equal. If one is observing a vector scope while playing back color bars, one would adjust equalization for the blue vector, matching the blue vectors to have the same distance out from center. One would adjust the DG controls using the yellow vector, matching the yellow vectors to have the same distance out from center.

If the quad machine has two controls in addition to the equalization control for each head, they will be called F and Q (Ampex nomenclature) or X and R (RCA nomenclature). These controls are somewhat more difficult to set, and they interact with each other and also the equalization control. F is the same as X, and Q is the same as R. Q and R are essentially differential gain, i.e., DG controls. F and X are essentially differential phase controls. They effect the color phase, i.e., hue, in the bright areas of the picture versus the dark areas of the picture. To adjust F and X one minimally needs a vector scope. As with DG, Q and R are adjusted while observing the yellow vector during color bar playback. They are adjusted to match the distance out from center of the four yellow vectors. F and X on the other hand, are also adjusted observing the yellow vector, but adjusted to match the rotational angles of the four vectors. The end goal is to adjust these controls, F and Q or X and R to blend the four yellow vectors from the four heads into one single ball (or, a dot, if the signal to noise of the tape is really good).

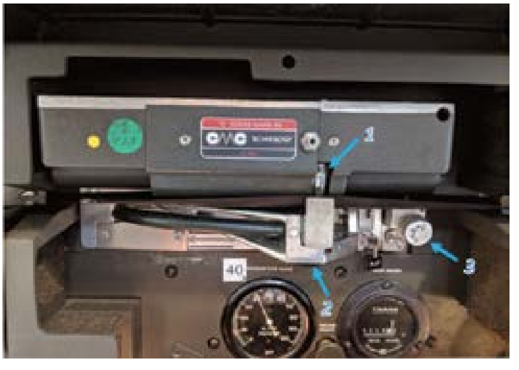


Figure 13. The head assembly on an Ampex model MK XV. Arrow 1 points to the head wheel. Arrow 2 points to the scallop adjustment; see figure 14 for an example of scalloping error. Arrow 3 points to the tip penetration adjustment.

There are two mechanical adjustments, *vertical guide* (or *scallop*) and *tip penetration*[30] (called *skew* in the documentation for RCA machines), as shown in figure 13. The four heads on the head wheel must be aligned with great precision. An error of even one micron is noticeable in the picture. If the timing (physical and electronic) of the start of each line is not accurate "scalloping error" results. All quad machines have an adjustment to correct for this. (If you encounter a tape that plays back with a scalloping error that cannot be corrected it is probably a duplicate with the error "baked in." This cannot be corrected).

30 The tip of each head protrudes from the plane of the tape face. This deforms the tape with an indent that creates a small dimple. While this increases level of the signal read from the tape, the physical distortion, however temporary, changes the physical dimensions of the system. This is one source of time base errors in quad playback. If the dimple indent is too deep, the penetration can go through the tape, creating a tear or full slice, permanently damaging the media.

Figure 14. Example of scalloping error.

Quad heads come into contact with the tape, slightly penetrating into the tape. Higher tip penetration however gives a strong signal from the tape. The mechanism for adjusting tip penetrations is shown on figure 13. If the tape is deformed too much, however, the heads can slice the tape; see figure 15.

Figure 15. Quad tape sliced by heads after encountering an incorrectly made splice.

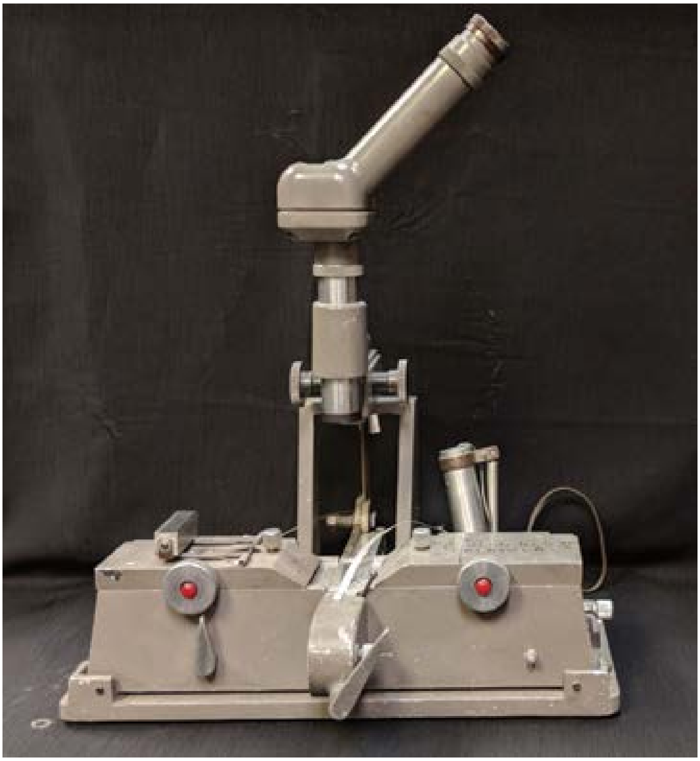


Figure 16. Block or jig of the type used to splice 2-inch tapes.[31]

There is a separate setting for each head that can be used to compensate for physical difference in the heads and uneven head wear, thus producing equal output for all four heads.

31 Additional information on splicing quad tapes is provided in *Videotape is not the only one to progress to extinction*, http://www.vtoldboys.com/evolve.htm, dated May 2, 2007 (accessed April 18, 2018).

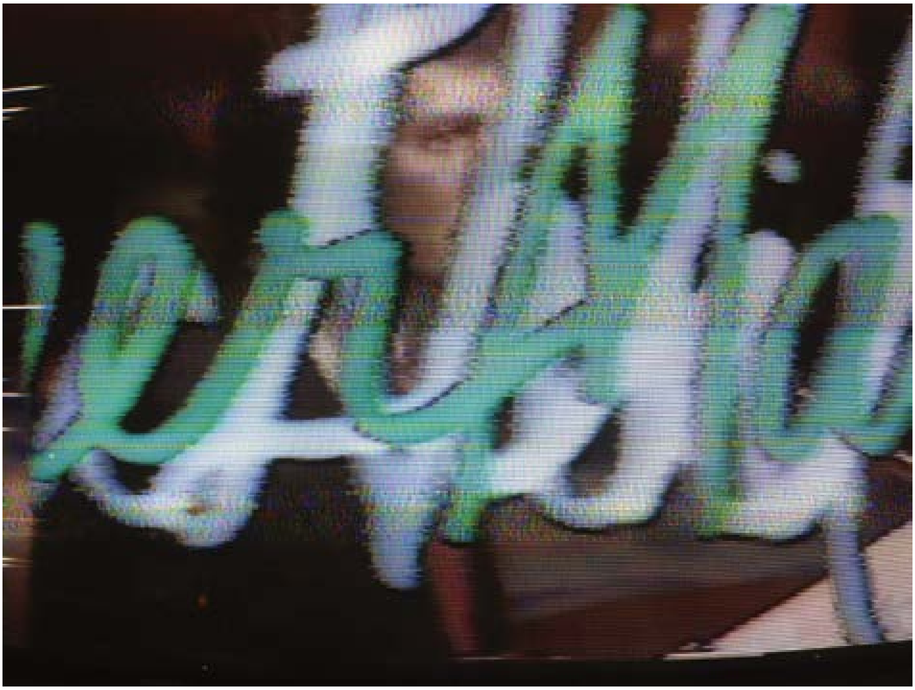


Figure 17. Not all defects can be corrected on playback. Here, for example, the image is marred by uneven horizontal lines, a sign that the tape was improperly recorded when created, with insufficient RF. This defect cannot be corrected.

C.2.7.2.2 Ampex illustrations of visual artefacts relating to VTR adjustments

The following illustrations from the maintenance manual for the Ampex AVR-3 VTRs show the effect of certain incorrect settings, with captions that suggest actions to correct the problems.

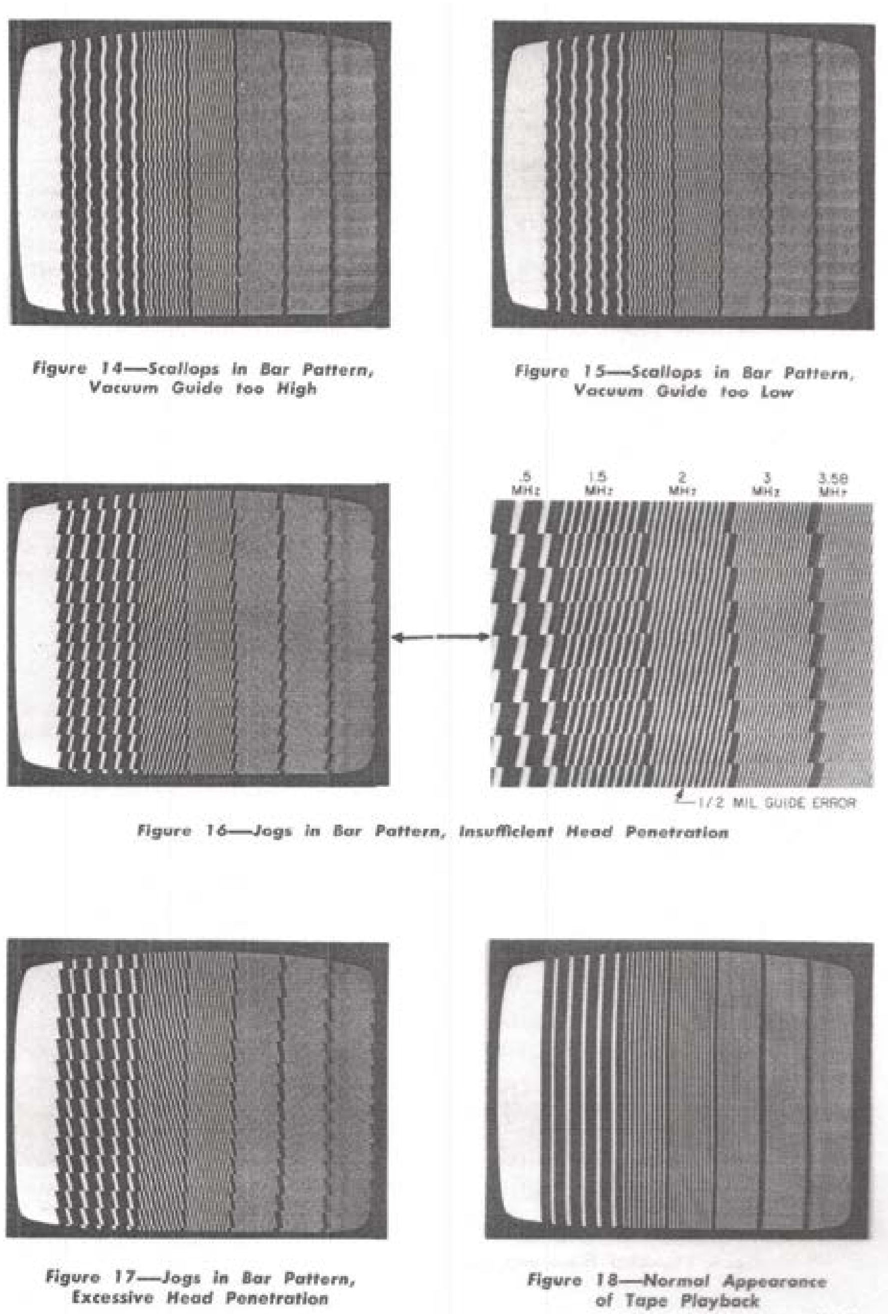


Figure 18. Page from an Ampex maintenance manual showing the effects of incorrect vacuum guide and head penetration settings.

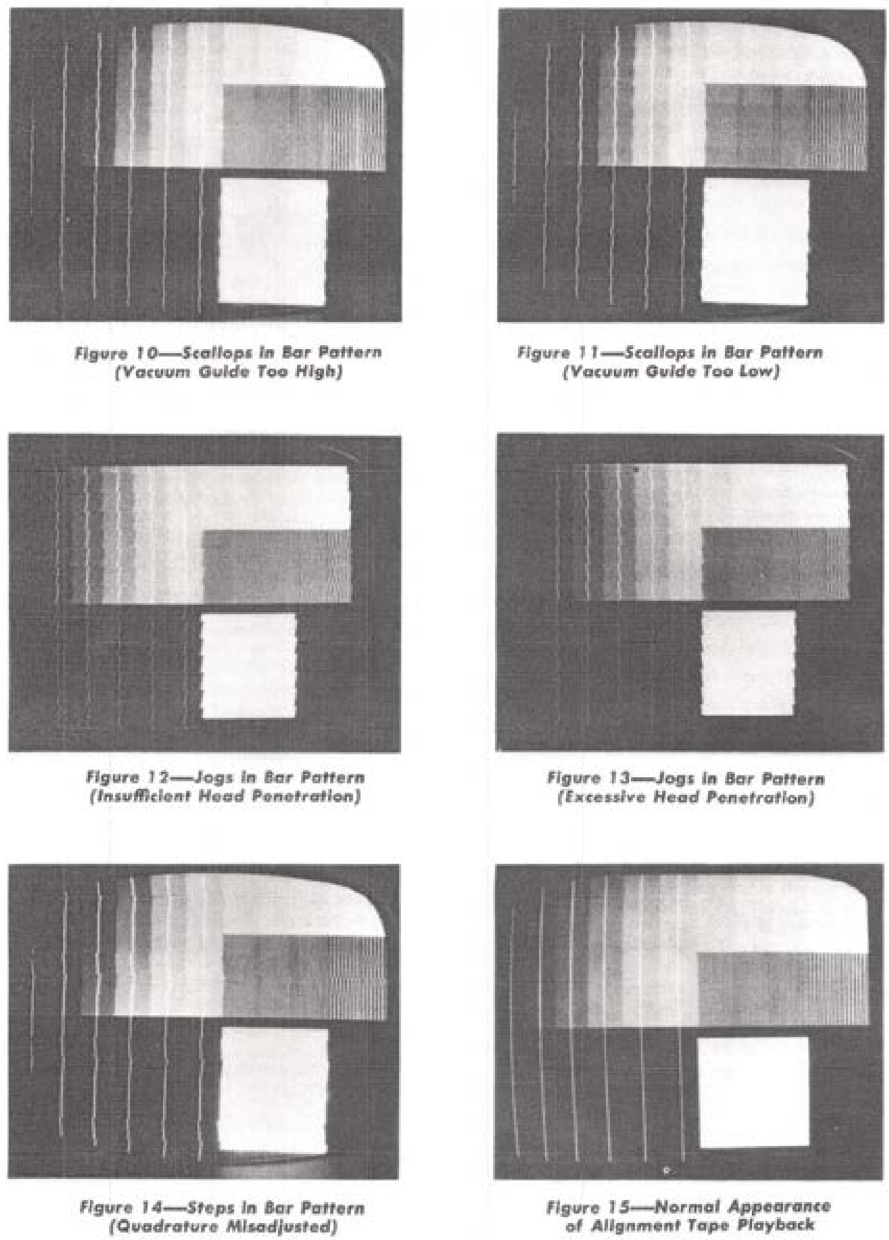


Figure 19. Page from an Ampex maintenance manual showing the effects of incorrect vacuum guide, head penetration, and quadrature settings.

C.2.7.2.3 Colour lock

Quad requires multiple external synchronisation sources, including horizontal and vertical sync (specific to the standard to be reproduced, such as 3.58 MHz for NTSC or 4.43 MHz for PAL). The machines require very-high-quality sync sources for both horizontal and vertical sync, because they depend on the external reference, rather than make much effort to resolve irregularities internally.

C.2.7.2.4 Skew

There is no *skew* on quad machines, using the term at it is used by video engineers today.[32] Skew in segmented formats is very different from skew in non-segmented formats, i.e., most helical formats. In most helical formats skew manifests itself as a horizontal displacement at either the top or bottom of the picture. It is manually adjusted by varying the tape tension or automatically corrected by the time base corrector. In segmented formats "skew" error appears multiple times within the picture each time a switch is made from one head to the next. In quad it is most closely equivalent to tip penetration error. Tip penetration error can be adjusted manually or automatically (in some machines), and is almost completely corrected by time base error correction.

Like all analogue videotape formats, quad is also dependent on its *control track*, a simple linear track that runs continuously with the video recording. It serves a similar function to sprocket holes on film for controlling linear speed and electro-mechanical synchronisation (see also section C.2.9). Loss of control track makes a tape unplayable. The sole exception is the Ampex AVR-1, introduced in 1970. It has an auto-track function that uses the amplitude of the RF signal being read by the video heads to recreate the control track function.[33] This feature was over a decade ahead of its time. The use of RF amplitude to determine track location is used in digital tape, such as DAT introduced in 1987.

C.2.8 Sound tracks

The quadruplex video format was developed by Ampex's professional division, a group that had been producing sound recording technology for more than a decade; its Model 200 audiotape recorder was first used for a Bing Crosby broadcast in 1948.[34] Since the quad tape generally travels longitudinally at 15 ips (7.5 ips is reserved for the less-common slow speed mode), the potential for high quality sound is in place. However, the audio performance of quad is comparable to, but not quite as good as, the best professional audio machines of the time. The shortfall results from the fact that quad tape has its "magnetic grain" oriented to optimize the transverse video tracks while sound signal is carried by the longitudinally oriented track, more or less at a right angle to the picture tracks. This mismatch in orientation of track to "grain" can cause as much as a 6dB loss in signal to noise. Furthermore, quad VTRs include many sources of electromagnetic interference that can be picked up by the sensitive audio head positioned to record the sound. Some VTRs go to great lengths to shield the audio head stack while others, e.g., the Ampex AVR-3, attempt to separately sense the interference and inject it out of phase into the reproduced audio in order to cancel out interference picked up by the head.

32 Readers should be attentive to variation in the usage of this term: the documentation for RCA quad VTRs manufactured from the 1950s to the 1980s uses *skew* to refer to what Ampex calls *tip penetration*.

33 The description of the Ampex AVR-1 at BroadcastStore,com reports, "There was an auto guide servo, auto tracking servo, auto standards selection, a time base corrector with an entire line of memory, and easy-to-use setup aids. The video head even had a retractable vacuum guide to facilitate tape threading." (BroadcastStore.com: n.d.)

34 Ampex Corporation, *Ampex History* (Ampex Corporation: n.d.).

It is worth saying that helical-scan formats, such as U-matic, VHS, and EIAJ (sections C.3, C.4, and C.5) have much slower linear tape speeds and less space on the tape reserved for audio tracks. As a result, the quality of the sound on these other formats is not as good as that recorded on quad tapes.

Nearly all quad tapes are monaural. In order to retain backward compatibility, stereo quad tapes divide the usual mono track in half.[35] There are quad tapes with stereo sound, but this will be at a lower inherent fidelity than the monaural recordings. Quad VTRs capable of playing stereo sound are very rare, and this can make arranging for a stereo transfer challenging for archives.

The quad specification includes a provision for a separate audio cue track. This is a utility track and not meant for broadcast. It was available for taking audio notes during recording, or leaving messages to the operator, among other uses. In about 1970, the cue track began to be used to carry SMPTE time code in editing systems.

C.2.9 Time code and control track on quadruplex videotape

Since the quad format predates the introduction of SMPTE time code, it has no dedicated SMPTE time code track unlike successor formats such as 1-inch Type B and Type C, where time code is carried on a special track or on a "spare" audio track (see section C.4), or Betacam, which was designed with a track dedicated to time code.

Quad has a control track that provides a continuous time reference for playback. It carries a 240 Hz reference frequency. The phase and amplitude of this reference frequency is used to align the segmented video tracks during recording and playback. However, the control track is not addressable, and it does not store any time- or location-specific information. One frame, second, minute, hour is the same as any other.

As noted in section C.2.8, the cue track on quadruplex videotapes began to be adopted as a location to carry SMPTE time code in about 1970.

C.2.10 Time factor for transfer of quadruplex video tapes

When setting up for and transferring a recording from a quad tape, many specialists report that total investment of time will require from two to three times the duration of the recorded program material. That is: expect to spend from one to one-and-a-half hours copying a thirty-minute show.

The preceding estimate assumes that the tape to be transferred is in a reasonably good condition and the VTR is well adjusted and operational. As discussed in section C.2.4.3, it is always advisable to clean quad tapes prior to transfer.

C.2.11 Time base and related forms of correction for quadruplex tapes

C.2.11.1 Dubbing via radio frequency (RF) transfer

Early low-band quad machines had an RF dubbing function. In this mode the signal on the tape could be copied to another machine without first being demodulated on playback and remodulated before recording. In practice the results were often unsatisfactory because, using this approach for signal transfer, it was difficult if not impossible to make adjustments to correct for problems with gain and scalloping, as outlined in sections C.2.7.2.1 and C.2.7.2.2 above. The residual gain and scalloping errors would then be "baked into" the new recording and could not be subsequently removed.

35 The same strategy was used for the Phillips Compact Audiocassette. Originally the format was mono. When stereo was introduced, to retain backward compatibility, the track was divided in half (minus the guard band between the two channels).

Mechanical errors, such as scalloping, can be completely removed by means of time base correction, a topic discussed in section C.2.11.3 below. Since the application of time base correction requires demodulating the signal, the RF dubbing feature was eliminated in quad VTRs as low-band-only models were replaced by models with high-band and super-high-band capabilities that also supported time base correction.

C.2.11.2 Monitoring options

Some quad machines have elements marked *EE*. This refers to a different capability than the *E-E mode* found on U-matic VTRs. On quads the EE marking indicates that the input to the machine is routed to the output, as differentiated from playing back from tape. Professional audio machines often permit recording engineers to (alternately) monitor the input or playback from the tape, to help ensure that the input is being successfully recorded. Some video machines offer the same *from-input* and *as-recorded* monitoring options and, in addition, offer the ability to monitor a static signal such as blue screen or bars, which indicates the VTR's output when not playing a tape, such as in pause or rewind.

C.2.11.3 Time base correction and enhancement functions

Time base correction (and related technologies) are discussed as a general topic in section D.1.3.1.4.2. That section explains that an ideal video transfer will maximize compliance with the RS-170 standard, first standardized in 1957 and described in section B.1.2.6. There are also PAL and SECAM equivalents to RS-170, all of which are intended to ensure that the luma and chroma levels and phases of a video signal are in the best possible conformance to broadcast requirements (see also section B.1.2.7). Failure to comply with RS-170 (or its equivalents) leads to a lack of stability that can cause picture breakup or even an aborted transfer, and the *time base corrector* (TBC) addresses this problem.

Time base errors arise when video, an electrical signal, is recorded onto videotape by a mechanical device. The electrical signals include features that must be "timed" with accuracy to the millionths of a second, i.e., with a precision that surpasses that of most mechanical devices. Early quad machines did not have time base correction. The problem was insufficiently understood, and the technology did not exist to perform the correction. Meanwhile, it is also the case that the timing problems with quad tapes differ a bit from those encountered with helical-scan formats such as U-matic, VHS, and EIAJ (sections C.3, C.4, and C.5).

Most helical-scan formats record a complete field or frame of video information in a single rotation of the drum. These formats suffer from large time instabilities or time base errors, but these errors appear at either the very top or very bottom of the picture. Quad, with the tape tightly held by the vacuum guide, has only small time base errors, but these errors are highly visible in the picture because so many head passes are necessary to make an entire video frame. Although quad and helical recording were originally developed at roughly the same time, the large time base errors in the helical formats were deemed to make them unfit for broadcast use. Only the development of digital time base correction, many years later, would reverse the banishment of helical scan from broadcast use.

Quad suffers from two very obvious forms of time base error that result from misalignment of the vacuum guide holding the tape in terms of the position of the rotating headwheel. In quad, the rotating heads actually penetrate the tape, causing a very small, temporary stretching of the tape. The amount of penetration depends on the closeness of the vacuum guide to the headwheel. Move the guide closer and the heads penetrate more deeply. Move the guide away and the head penetrate more shallowly.

The amount of penetration on playback must match the amount of penetration during record. Since the penetration stretches the tape, it effectively makes the tape longer, and thus reduces the effective head to tape speed. A "head to tape" speed error causes the playback head to reproduce either too little or too much information as it scans across the width of the tape. This causes a very visible discontinuity in the image where the switch from one head to next occurs. Originally, RCA called these errors *jogs*, and illustrative examples are included in figure 18.

Some later quad VTRs have an automatic servo to adjust the position of the vacuum guide to eliminate this type of error. It is known as automatic tip penetration or Autocomp.

A second type of error occurs if the vacuum guide is not concentric with the rotating headwheel. An error in concentricity, i.e., the height of the vacuum guide versus the headwheel, causes the head penetration at the top of the tape to be different from the head penetration at the bottom. In this case, there will be no discontinuity when switching from one head to the next, but rather a horizontal shift in the picture during each head pass giving vertical edges in the picture a scalloped shape.

Both of these errors can be substantially removed from the picture using time base correction. Originally this type of correction was accomplished in two stages using electronically variable delay lines. In the first stage, horizontal sync in the reproduced video is compared with a stable reference. The measured timing error is used to change the length of a variable delay line to compensate for the error. At the output of this stage, the phase of the colour burst is sampled and compared to a stable reference and the resulting error is applied to a second delay line making even finer correction. RCA calls these two systems *Monochrome Automatic Timing Correction* (MATC) and *Colour Automatic Timing Correction* (CATC). Ampex calls them Amtec and Colortec.

In later quad machines, the first stage of correction was accomplished by switching various length delay lines in and out of the signal path. Still later, both stages of correction were accomplished by digitizing the video and loading into and reading it out of computer RAM. Computer RAM can provide a huge correction range, but this is generally unnecessary for quad.

Readers should note that both the horizontal sync and the colour burst occur at the start of the scan line, i.e., at the left side of the picture. (Aspects of picture synchronisation including colour burst are treated in section B.1.2.6.) Regarding the two types of vacuum guide position error discussed above, it is the case that timing error will accumulate during the scanning line but will not be corrected until the start of the next line. Meanwhile, errors in overall head tip penetration cause an error that is consistent over the entire head pass. This produces a hue shift at the right side of the picture vs. the left side. Error in guide height produces an error that goes in one direction at the start of the head pass gradually becomes an error in the opposite direction at the bottom of the head pass. This produces a hue shift at the right side of the picture that is one way at the top of the head pass and the other way at the bottom. This is very noticeable.

A third type of time base correction is called *velocity error compensation*. Velocity compensation estimates how the error will change over the course of the scan line and applies a linearly changing correction during the line. If the estimation is correct, errors seen at the right side of the picture will be corrected. It is called velocity error correction because the source of these artefacts is an error in head-to-tape speed, or velocity.

In a perfect world, what one would want is a way to measure time base errors continuously during the active line. This is what the *pilot signal* (sometimes called *pilot carrier* or *pilot tone*[36]) provides in the quad format's mode called *super-high-band with pilot*

36 See the Wikipedia article Pilot signal, https://en.wikipedia.org/wiki/Pilot_signal, accessed 15 April 2018.

(sometimes abbreviated as SHBP). The pilot signal is a totally unmodulated, high frequency subcarrier, higher than any frequency in the video, mixed into the video, and recorded along with the video. Upon reproduction, any timing error seen in the pilot when compared to a stable reference indicates the instantaneous time base error in the reproduced video. Using the pilot to help manage the transfer of the video signal puts near-perfect time base correction in reach. Sadly, SHBP was developed at the very end of the life of the format and was hardly ever used.

Superior results were more widely achieved when digital storage and analogue-to-digital conversion became available in the mid-1970s. Although Ampex shipped digital time base correctors as early as 1967 it was as an extra-cost accessory. The Ampex AVR-1 has an analogue time base corrector while the AVR-2 (1974) and -3 (1975) have digital time base correctors as standard equipment.

C.2.11.4 Dropout compensation

Dropout compensators appear in both Ampex and RCA quad machines around 1965. The topic of dropout compensation and its role in preservation digitisation is discussed in some detail in two segments of the section devoted to 1-inch helical scan carriers (C.4.3.3.2 and C.4.4.3.2), as well as in the section devoted to U-matic videocassettes (C.5.12.2.1).

C.2.11.5 Noise reduction

Quad VTRs do not offer a native noise reduction system.

Figure 20. The granddaughter of this section's main author stands in front of a forty-year-old Ampex quadruplex VTR, expressing frustration at the many problems her grandfather must overcome in order to keep the device in operation.

C.3 C.3 EIAJ AND SONY CV ½-INCH OPEN REEL VIDEOTAPES

C.3.1 Introduction

The first commercially viable videotape introduced in 1956, the quadruplex ("quad") format, together with the VTRs required to record and play it, was very expensive. Nonetheless, the medium's ability to offer immediate replay, negating the time or expense required to develop camera film, and the compatibility of the resulting recording with television standards, proved the value and utility of videotape. It was only natural to expect that lower cost alternatives to quad would become available, especially to serve non-broadcast applications, even if the quality failed to match the professional machines. Throughout the 1960s and early 1970s a variety of smaller and lower cost formats were developed in an attempt to establish this segment of the market. Initially, Shibodan, Panasonic, General Electric, Concord, Sony, and others promulgated ½-inch proprietary reel-to-reel formats until the 1969 release of a standard by the Electronic Industry Association of Japan (EIAJ).[37]

Sony Corporation was the most successful vendor of both the *EIAJ type 1* (black and white) and the later *EIAJ type 2* (colour, ca. 1974) variants. This chapter also presents information on the earlier Sony proprietary format *CV*, dating from about 1965. An additional format, often called *Sony skip field*, may be present in collections of EIAJ tapes and what may appear to be a poor playback situation may instead be this other Sony-related format.

C.3 Figure 1. Picture when CV is played on EIAJ.

37 The Electronic Industries Association of Japan (EIAJ) was founded in 1948 and, in 2000, merged into the Japan Electronics and Information Technology Industries Association (JEITA). The IASA-TC 06 authors have been unable to identify the specific EIAJ standard number for this format. A very complete English translation of the standard, with multiple diagrams, was published in the December 1970 issue of the *Journal of the SMPTE* (vol. 79, issue 12; DOI: 10.5594/J00848). The authors have not identified any form of standardisation for the colour version of the EIAJ format. Sources of information about the formats variously refer to the monochrome version as EIAJ type I, EIAJ type 1, or EIAJ-1 and the colour as EIAJ type II, EIAJ type 2, or EIAJ-2; this guideline uses *EIAJ type 1* and *EIAJ type 2*.

C.3 Figure 2. Picture when EIAJ is played on CV.

The CV format records only the first field in a video frame. *[Note to readers: this may only be the case in NTSC, and in PAL both fields may be recorded. Comments welcome.]* There are two heads on the drum, but during recording only one head records. On playback both heads read the same information; that is, the single field recorded. To achieve signal continuity the tape wrap is greater (186 degrees instead of 180 degrees), and the second head is offset by 6 degrees. These two mechanical features allow the single recorded field to be read twice, providing 2 fields for playback. This explains why the image on such recordings lacks detail and is "soft".

EIAJ videotape was used in many applications. Its low cost and relative ease of use, with comparatively small, lightweight VTRs made it accessible, and copies may be found in collections of training videos, sports games, promotional video, commercial distribution, corporate communications, artists, anthropological and other research settings, small television facilities found in schools, as well as early community and public broadcasting stations.[38]

C.3.2 Selection of best copy

The resolution of this format is very low, and the image often unstable. A copy of one of these tapes is very unsatisfactory. Given their use by artists, anthropologists, and for the capture of sports for study, it is prudent to assume that the tape under examination is the original as copies were rarely made or used. Exceptions might be training and corporate communication tapes intended for limited distribution.

Common indicators of poor playback and multiple generation copies include the following:

- Inherent in the technology that recorded EIAJ tapes is a head switching "error," which might also be considered to be a characteristic of the format. The error's effect is manifested in a small number of lines at the bottom of the picture that appear offset from the image. When viewing EIAJ recordings on the 90 degree deflection tube monitors that were contemporary with these machines, the lines would have been hidden from the user behind the bezel. When a copy is made, an additional set of switching error lines appears at the bottom of the screen. By counting the offsets you can count how many generations of copy you have. However, since U-matic also exhibits the same

38 EIAJ may be found to contain off-air broadcast recordings. Archives should be aware of the copyright issues affecting such recordings and consider how their country's laws impact preservation through digitisation.

artefact, the presence of multiple offsets on a U-matic copy may well indicate a copy, but it does not indicate what source format was, or whether those copies were made on the U-matic or on the original EIAJ recorder.

- Like other analogue video formats, 1/2-inch tapes may exhibit issues in playback, related to tape tension precision, or to variation from one playback VTR to another.
  - *Flagging*: the top of the image leans to the left or right. This is caused by uneven or inconsistent tape tension or differences between the record and playback machines. Adjust the skew on the playback machine to compensate for this error. If you adjust the skew and the flagging does not change, you may have a copy where the flagging is recorded onto the tape.
  - *Rolling*: the vertical blanking interval scrolls up or down the screen (the picture "rolls"). This may be caused by mistiming between the location of the tape and the head drum, and skew adjustment may correct the problem. Alternatively, there may be a mechanical mismatch between the original recording VTR and the VTR used for playback. In this case, correction may require pulley replacement as discussed in C.3.4 below.
  - Other visible artefacts may be corrected by use of a time base corrector.

C.3.3 Cleaning and carrier restoration

Sony tapes, the most common, are usually labelled V-30, V-31, V-32, V-30H or V-32H, the number denoting only differing packing, reel size or length. Other manufacturers also manufactured tape, including Ampex, Memorex, 3M, and Panasonic, among others. The tape brand and tape type alone will not identify the video format on the media.

Tapes used for all ½-inch reel-to-reel video formats generally shed oxide and are often sticky. It is advisable to bake and clean all tapes prior to attempting playback. Failure to clean the tapes prior to playback will lead to accumulation of oxide on the guides that has an adverse effect on playback, leading to speed errors that affect image stability and head clogging. The procedure for baking is the same as for any other tape (see section C.1.3.4.2). However, as shedding and stickiness are common, longer than normal treatment time is expected. Thoroughly cleaning the playback machines between each tape is recommended. Both the oxide and back coating shed.

Many factors affect tape baking, well described in a comprehensive report by the Image Permanence Institute (Bigourdan, Reilly, Santoro, and Salesin: 2006). In addition, tape formulations vary over time and the audiovisual expert Dietrich Schüller proposes the underlying problem lies with changes in the manufacturing process, rather than the agents themselves. His research includes extended oral histories with technicians who worked in the tape manufacturing plants (Schüller: 2014). Playback machine transport, humidity in the playback environment, extent and method of tape cleaning (manual, with Pellon, with or without a stainless steel or sapphire blade, etc.) can all impact tape replay.

The prevalence of tape binder degradation in problematic formats such as EIAJ-family media has led to a variety of approaches to the treatment of those tapes; see section C.1.3 for general information on carrier assessment, preparation, and cleaning. Like all PU tapes, routine re-spooling and baking for more than one cycle is a very common treatment. Some workers replay tapes hot, and report that the shedding increases measurably as the tapes cool, while other technicians insist tapes should cool to room temperature prior to playback. \Though in some tape formulations the stickiness becomes so severe layers will adhere, binder-base adhesion failure is not as common in EIAJ as in ¼-inch audiotape, so careful re-spooling as part of the inspection may well be appropriate to these media.

Unlike cartridge-based formats such as U-matic, Betacam, and DV, cleaning machines for ½-inch reel-to-reel videotapes were never common. Recortec also made a version of their cleaning machine for ½-inch tape. Bow Industries[39] makes a version of their Model 432 ½-inch tape cleaning machine specifically for this format. Otherwise the tapes can be cleaned by hand on a ½-inch audiotape transport, with Pellon and alcohol. This can be performed on an unmodified machine, though removing the head block, if the transport logic will allow, is desirable to protect that key component of the machine. The Studer A80 transport is especially suited to this task as it has plenty of open space to work with, and gracefully handles the uneven tension caused by the human hand. Only operators trained and experienced with the procedures should attempt to clean by hand, as a great deal of damage can be done to a tape very quickly. Common damage from this method is stretching or otherwise deforming the tape. Its polyester base will stretch rather than break like acetate-based tape. This is not repairable. Failure to regularly change the Pellon may scratch the tape or leave clumps of shedding oxide or back coating on the surface of the tape, degrading playback. Dedicated cleaners are machined for even tension and the Pellon rolls automatically rotate, taking debris away from the tape.

C.3 Figure 3. Cleaning by hand with Pellon fabric.

Warning: great caution is warranted with this cleaning method.

39 *Bow Industries Incorporated*, http://www.bowindustries.com/, accessed 9 December 2016.

C.3.4 Replay equipment (playback VTRs)

No new VTRs have been manufactured since approximately 1980. The following Sony models are most commonly found:

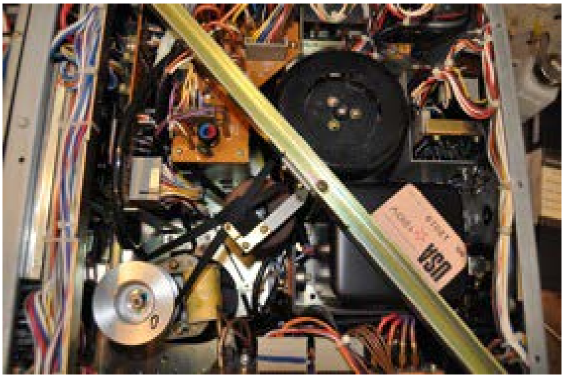
NTSC:

- CV-2100 (skip field format)[40]
- AV-3650 (EIAJ type 1, B&W)
- AV-8650 (EIAJ type 2, colour)

PAL

- CV-2100 (same model number used for both PAL and NTSC)
- AV-3620, -3670 (EIAJ type 1, B&W)
- AV-8670 (EIAJ, type 2, colour)

When digitising these tapes, archivists should be aware that Sony expected these VTRs to be used in isolation. That is, tapes were recorded and played on the same machine. Veteran video engineer John Turner remembers a letter from Sony stating there was no expectation of interoperability, i.e., playing back a tape that had been recorded on one VTR on another. Most problems encountered are due to this lack of interoperability. A single motor drives both the capstan (forward tape motion) and the rotation of the scanner (heads performing a helical scan on the tape). The synchronisation of these two components is critical for accurate playback. Small differences exist due to machining tolerances (i.e., parts are not the same size), the very crude mechanism by which a belt from the capstan also drives the scanner, and the very simple, poorly regulated electronics throughout the machine. A time base corrector is a minimum requirement. Under ideal circumstances multiple machines are available for playback, wherein by trial and error the best match is found.



C.3 Figure 4. Internal view of ½-inch VTR, showing pulley and drive belt.

40 Sony also produced pre-EIAJ "skip field" machines identified by model numbers that start with DV. These playback-only machines often lack even basic fast-forward and rewind, other than via a hand crank. Machines identified by model numbers that start with CV will record and playback tapes.

For severely out of alignment tapes, it is possible to machine various sizes of pulleys for the capstan to change the speed relationship between the linear tape speed as determined by the capstan and the scan rate of the head. By changing the size of the pulley, the ratio of the rate of spin of the capstan will change in relation to the spin of the scanner.

C.3 Figure 5. Capstan and drive for ½-inch VTR, with custom replacement capstans.
Top: internal view of ½-inch VTR, showing capstan pulley and drive belt; bottom: set of custom-machined capstan pulleys in slightly different diameters.

C.3.5 Use of time base correctors (TBCs) for ½-inch open reel videotapes

Significantly better time base correction is provided by TBCs from the 1970s and 1980s than by later models. Experienced engineers favour models like the Sony BVT-810, designed for use with U-matic decks, and the DPS-230/235 standalone TBCs. These units will accept and correct the lower grade signals found on ½-inch tapes, i.e., they will generally lock to the unstable EIAJ signal. In contrast, later-model TBCs were designed to correct the superior recording that typifies tapes from the last decade of the analogue era, and they may not be able to lock onto an EIAJ signal. Meanwhile, specialists often trade anecdotes about newer TBCs trying to output colour from an EIAJ type 1 signal that may be traceable to this consideration. In any case, to eliminate the chroma artefact, we recommended that if the input signal is B&W, the chroma controls should be turned off, or turned to their minimum setting.

Among the ½-inch open reel formats, the only cross compatibility between formats is that EIAJ type 2 tapes can be played on type 1 machines, though with only monochrome reproduction and the same interoperability issues just discussed.

C.3.6 ½-inch open reel recording formats

C.3.6.1 List of ½-inch formats

EIAJ type 1 is the most common of all ½-inch open reel video formats. Other formats that also use ½-inch open reel videotape include:

- Panasonic "12 ips"
- Shibaden
- Concord
- Sony CV "skip field"
- EIAJ type 2

C.3.6.2 Feature comparison for CV, EIAJ type 1, and EIAJ type 2 videotapes

C.3 Table 1. Feature comparison table for CV, EIAJ type 1, and EIAJ type 2 videotapes
[Note to readers: It has been difficult to find the information needed to complete this table. The information in bold is unconfirmed and there are blanks. Input will be appreciated.]

System Data	CV	EIAJ type 1	EIAJ type 2
Drum diameter>	116.97 mm	115.824 mm	115.824 mm
Speed of head drum	1500 rpm (P), 1800 rpm (N)	1500 rpm (P), 1800 rpm (N)	1500 rpm (P), 1800 rpm (N)
Video head to tape speed	? m/s	? m/s (P), ? (N)	? m/s (P), ? (N)
Tape speed (standard play)	29.14 cm/s (P)	19.05 cm/s (N), 16.322mm/s (P)	19.05 cm/s (N), 16.322mm/s (P)
Video head gap	0.4 microns	0.4 microns	0.3 microns
Video head azimuth	+/- 15 degrees	+/- 20 degrees	+/- 6 degrees
Mono audio track width	0.65 mm	1.05 mm	1 mm
Audio frequency response	80 Hz - 10 kHz	80 Hz - 10 kHz	-
Control track width	?	0.6 mm	0.75 mm
Maximum recording time	40 min	60 minutes	60 minutes
S/N Ratio - B/W	> 40 dB (CCIR 421-1)	> 40 dB	> 40 dB
Horizontal resolution	240 lines	300 lines	240 lines
Tape wrap	186 degrees	180 degrees	180 degrees
Angle of video tracks	2 degrees 5 minutes	5 degrees 00 minutes stationary, 5 degrees 58 minutes moving	5 degrees 56 minutes stationary, 5 degrees 57 minutes moving
End sensor leader	Mechanical	none	none

C.3.7 Maintenance of ½-inch playback VTRs

An archivist working with any ½-inch EIAJ tape should expect the tape to shed and be sticky. After baking or dehydration to treat sticky-shed syndrome, many audio, video, and data tapes exhibit little shedding. Alas, ½-inch open-reel videotapes do not follow this behaviour and should always be cleaned after baking. Even small amounts of shedding lead to signal loss and transport contamination. Furthermore, cleaning allows the operator to examine the tape for possible additional faults, including splice failures, blocking, severe oxide or back coating losses, and other degradation requiring attention prior to playback.

As with all video playback equipment, EIAJ machines should be kept scrupulously clean. After each playback a thorough cleaning of any part of the machine that touches the tape should be performed. Periodically remove the front panel and clean debris that accumulates, especially oxide shed. Also, remove the bottom cover and vacuum away any dust and debris that accumulates there. An experienced technician should lubricate the moving parts as part of routine maintenance or troubleshooting playback issues.

It is important for heads to have ample tip depth for quality playback. The original signal is poor and playback is not tolerant of worn heads. There are very few facilities remaining providing EIAJ heads.[41]

Parts are extremely scarce. In addition to the heads, drive belts also show the effect of aging. When properly fitted, the belt is crosses over itself. The belt is fitted with a special part to minimize static electricity. Static electricity can cause damage to semiconductors and disturb the RF signal, causing image artefacts. If this occurs during recording, it will be permanently captured in the recording. These critical components are not available new.

C.3 Figure 6. Cross-over belt and anti-static mechanism inside a ½-inch open reel VTR.

The pinch roller can be refurbished by any supplier who provides this service for audio or other capstan/pinch roller assemblies. Examine the pinch roller carefully. There should be either the number 50 or 60 on the side. There are different pinch rollers for the 50 Hz (PAL format) machines and the 60 Hz (NTSC format) machines. Depending on their composition, pinch rollers fail by getting glazed, hard, tacky or melting. Factory pinch rollers on these machines get glazed and hard.[42]

41 As of this writing two suppliers are known to refurbish CV and EIAJ heads: AheadTek, http://www.aheadtek.com/, and Videomagnetics, Inc., http://www.videomagnetics.com/, both accessed 9 December 2017.

42 As of this writing, pinch rollers can be refurbished with fresh polyurethane by Terry Witt at Terry's Rubber Rollers in Sparta, Michigan, http://www.terrysrubberrollers.com, accessed 9 December 2017.

If many tapes are to be digitised it may be desirable to update some of the connectors on the VTR, including the power cord socket, RF, and audio outputs. Changing these connectors allows the use of modern cables without adaptors and improves the safety of the power mains connection. Further the audio and video connectors oxidize over time. Brand new connectors of the type used in the interfacing equipment will transmit the signal with higher quality than the factory original parts.

C.3 Figure 7. Sony AV 3/8650 back connector panel before and after connector upgrades.

C.3.8 Equipment alignment and calibration tapes and test media

Alignment tapes are extremely rare. Fortunately, the simple nature of the machines means with a service manual and common video tools a video technician capable of component-level repairs should be able to keep a machine running. A dihedral jig (for aligning the location of the heads exactly 180 degrees apart) is the most exotic tool required.

C.3.9 Sound tracks

There is a single, mono audio track on all ½-inch open reel videotape formats, with the exception of stereo on the very late model Sony VR-420.

There is no provision for audio noise reduction in any ½-inch open reel videotape format.

C.3.10 Time code and external control

There is no provision for SMPTE time code or external control in any ½-inch open reel videotape format.

C.3 Figure 8. From the EIAJ-1 specification: figures 1-4, table 1.

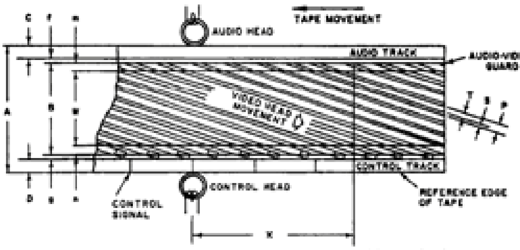


Fig. 1. Magnetic tape pattern (tape seen from magneto-sensitive surface).

Item	*Dimension (mm)*	*Item*	*Dimension (mm)*	*Item*	*Dimension (mm)*
A	$12.7^{+0.0}_{-0.1}$	*m*	0.275	*D*	0.8
B	10.65	*W*	10.10	*P*	0.173
C	$1.0^{+0.0}_{-0.0}$	*n*	0.275	*S*	0.04 plus
f	0.15	*g*	0.1	*T*	0.1 plus
				X	81.0

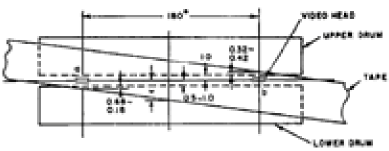


Fig. 2. Drum, video head and tape position.

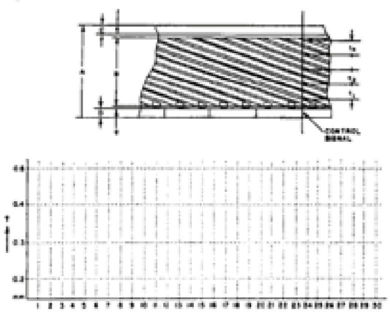


Fig. 3. Tape format.

x_f = 39.94, V_t = 190.5, = 3°7′43″, t_0 = 0.3474 (mm)

Table 1. Mechanical Specifications.

Item, Units	Dimension
1. (*A*) Tape width, mm	$12.7^{+0}_{-0.1}$
2. (V_t) Tape speed, mm/sec	190.5 ± 0.5%
3. (φ) Drum diameter, mm	115.82 ± 0.01
4. (V_h) Writing speed, m/sec	11.1
5. (*P*) Video track pitch, mm	0.173
6. (*B*) Tape width used for video, mm	10.65
7. (*W*) Video width (one field), mm	10.10
8. (*C*) Audio track width, mm	1.0
9. (*D*) Control track width, mm	0.8
10. (*f*) Audio guard bandwidth to video, mm	0.15
11. (*g*) Control guard bandwidth to video, mm	0.1
12. (*m*) Beginning of scan overlap width, mm	0.275
13. (*n*) End of scan overlap width, mm	0.275
14. (θ_0) Video track angle (tape not moving)	3° 11′
15. (θ) Video track angle (tape moving)	3° 7′ 43″
16. (*l*) Video track length (one field), mm	185.1
17. (*X*) Audio and control head position (see Fig. 7), mm	81.0

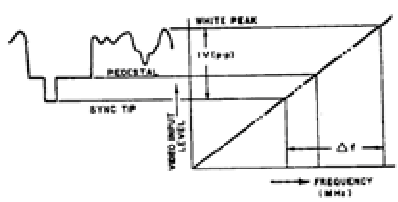


Fig. 4. Video-FM characteristic.

C.3 Figure 9. From the EIAJ-1 specification: figures 5-9.

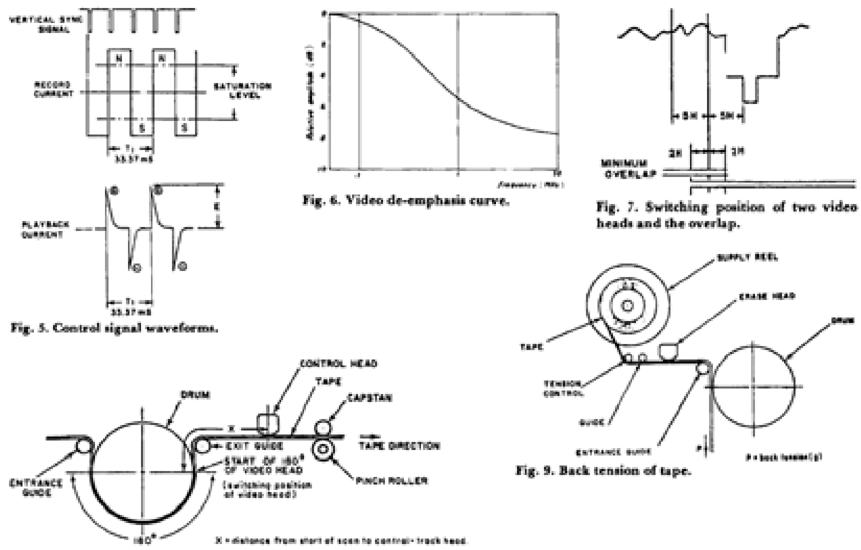


Fig. 5. Control signal waveforms.

Fig. 6. Video de-emphasis curve.

Fig. 7. Switching position of two video heads and the overlap.

Fig. 8. Position of audio and control head.

Fig. 9. Back tension of tape.

C.4 1-INCH HELICAL-SCAN OPEN REEL VIDEOTAPES

C.4.1 Background

Helical-scan machines recording video on 1-inch (25.4 mm) open reel tape became available beginning in 1962. At that time, however, they were proprietary in format, and remained so until 1965, when the first standardised models were introduced. For playback, the early proprietary formats require a working VTR of the same type used to record the tape. Examples include the Machtronics MVC-10, the Precision Instruments PI-3V, Sony's EV-200 and the EL-3400 from Philips (Weiner: 2011). Tapes from this period are exceptionally rare, and this chapter provides little further information about them other than that which applies generally to the care of 1-inch tapes.

In 1965, Ampex introduced what was eventually called 1-inch type A that, although not standardized in a strict sense, had a sufficiently open specification to permit other companies to produce type A VTRs. Ampex never proposed their specification to SMPTE as a standard, and the format was not referred to as "type A" until types B and C were standardized by SMPTE and there was a need to refer to their predecessor in an understandable way.[43]

Type A was a format that met with mixed success and limited broadcast industry uptake. The machine's cutting edge 1960s technologies were beleaguered with maintenance problems and, in spite of the standardised approach, the recorded tapes were not always compatible with other machines of the same or similar model. These problems were not really resolved until near the end of the life of the format. However, the low machine and tape costs made it popular, particularly in the educational and industrial market.

The SMPTE recommended practices paper describing Type B video was announced in 1977 and proposed for standardisation the following year.[44] The guidelines described a format already in production by the Robert Bosch Corporation/Fernseh Group and known as the "BCN" one-inch helical VTR format. The SMPTE Helical Recording Subcommittee was formed to have oversight of the guidelines. It was charged with the responsibility of revising or writing new draft ANSI standards and SMPTE guidelines for types A, B, and C one-inch and other helical-scan videotape recorder formats.

43 Type A standardisation (or the lack thereof) is explored in a 2015 forum thread by the video specialist Ted Langdell, http://mail.quadvideotapegroup.com/pipermail/quadlist_quadvideotapegroup.com/2015-April/008663.html, accessed 9 December 2017. Meanwhile, Tim Stoffel, another specialist, provides this comment regarding type A time code, "Provisions existed in the format for an address track," http://www.lionlamb.us/quad/format.html#1instd (scroll to type A), accessed 9 December 2017.

44 "Specifications Drafted for One-Inch Type B Helical Video Tape Recording Standards," *SMPTE Journal*, Vol. 86, November 1977, p. 842, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7241698, accessed 9 December 2017.

The Subcommittee proposed a number of recommended practices and standards associated with type C in its journal in the same year as it did for type B.[45] The 1-inch type C format was based on a common set of agreements that were developed jointly by Sony and Ampex. The major issues in the negotiation were the diameter of the head drum and the method of recording the vertical synchronising signal. Ampex eventually adopted the 1.5-head system favoured by Sony, and Sony accepted Ampex's 134.620mm (5.3 inch) head drum, as compared to Sony's former preference for 135mm (Mee, Daniel, and Clark: 1999).

Sidebar: SMPTE standards for 1-inch helical-scan, open reel formats

As noted above, there are no SMPTE standards for Ampex's type *A* videotype, although the format's existence and specifications are acknowledged by reference in SMPTE documents. The selection of the type designations *B* and *C* indicates SMPTE and the industry's recognition that type A was their predecessor.

The latest versions of the SMPTE standards pertaining to type B were published in 1998 and archived (retired) by SMPTE in 2004:

- ST 15:1998 (Archived 2004). *Television Analog Recording – 1-in Type B Helical Scan - Basic System Parameters*
- ST 16:1998 (Archived 2004). *Television Analog Recording – 1-in Type B Helical Scan - Records*
- ST 17:1998 (Archived 2004). *Television Analog Recording – 1-in Type B Helical Scan - Frequency Response and Operating Level*

The latest versions of the SMPTE standards pertaining to type C were published in 2003 and archived (retired) by SMPTE in 2010:

- ST 18:2003 (Archived 2010). *Television Analog Recording – 1-in Type C – Basic System and Transport Geometry Parameters*
- ST 19:2003 (Archived 2010). *Television Analog Recording – 1-in Type C – Records*
- ST 20:2003 (Archived 2010). *Television Analog Recording – 1-in Type C Recorders and Reproducers – Longitudinal Audio Characteristics*

After the development of types B and C, 1-inch helical-scan, open-reel tape became the dominant standard in video and broadcast television. It remained the most widely used professional video format for around twenty years. In 1992, the European Broadcast Union (EBU) stated, "24.5 mm (one inch) formats B and C are currently accepted, worldwide, as studio standards" (EBU: 1992a, p. 41). Although types B and C were used throughout the world, type B was the most commonly used machine among European broadcasters while type C came to be the accepted standard throughout the rest of the world.

There were later 1-inch VTRs that offered higher performance specification but did not comply with SMPTE standards. One example is the International Video Corporation's (IVC) 1-inch VTR, the IVC 1-11, introduced in 1980. The IVC 1-11 was a high-band colour machine claiming 49dB video SNR and two channels of Dolby encoded audio at a 55dB SNR (Abramson: 2003).

45 "Draft American National Standard: Basic System and Transport Geometry Parameters for 1-in Type C Helical-Scan Video Tape Recording, Proposed SMPTE Recommended Practice: Tracking-Control Record for 1-in Type C Helical-Scan Video Tape Recording, and Proposed SMPTE Recommended Practice: Video Record Parameters for 1-in Type C Helical-Scan Video Tape Recording," *SMPTE Journal*, March 1978, Vol. 87, pp. 163-168, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7241495, accessed 9 December 2017.

Readers are encouraged to consult section C.4.6 (*Distinguishing between tape types*) for a detailed look at the different ways recording tracks are laid down on type A, B, and C tapes, all of which employ magnetic media of the same gauge.

C.4.2 Type A

C.4.2.1 Introduction

Type A machines were introduced in 1965 by Ampex, who continued production until 1976 when they withdrew machines from sale and began converting the last of their stock to type C compliant machines. Over that period, they produced more than 30 models of type A machine, after which a third party company by the name of *Video Memories* had the right to build and sell the Ampex type A machines (Nmungwun: 1989). Other manufacturers of type A machines include Sony, but only at the end of the type A format life in 1976.

Type A video was recorded on 1-inch open-reel tape using a helical scan system (rotating head). It was a non-segmented video format, i.e., it was recorded one field per drum rotation using a single video head. The tape wrapped nearly completely around the head drum, in what is described as an *alpha wrap*, because the tape path resembles the Greek letter alpha.

The single head and alpha wrap design had one unfortunate effect: the head on the rotating drum leaves the tape on one side, crosses a small gap, and then reconnects and synchronises with the tape. Thus, for a fraction of a second, the video signal is lost, but continuity is maintained by synchronising the gap with the vertical blanking interval and reconstituting and inserting the sync pulse. When the type A machine was being manufactured, the technical complexity and cost of producing the delay lines that could store an entire field (a consequence of the single head) made time base correction impractical (Mee, Daniel, and Clark: 1999). The consequent drop in signal and the missing vertical blanking interval meant that type A recordings did not comply with US and European broadcast standards, a limitation that constrained the format's market. Type A systems were primarily sold to the education and industrial markets as a smaller and less expensive alternative to the higher quality 2-inch quadruplex VTRs.

The earlier models, such as the Ampex VPR-1, recorded and played back only in black and white, though later type A machines would record colour information in a subcarrier and it was possible to add an optional heterodyne or "colour under" add-on playback system that could decode the colour information. Late generation machines had an additional external time base correction device that made the type A machines usable in production facilities.[46] However, this combination was short lived, and quickly replaced with the type C machine.

C.4.2.2 Selection of best copy

Type A video was not a format suitable or intended for commercial replication, copies will only exist in circumstances where an operator had access to two machines and made copies one by one. In spite of its incompatibility with broadcast standards the type A recorder was used in production environments to both record takes and assemble program material. The device was not really portable but there may be original raw footage or production elements and the final master could exist on another format. If this is the case, normal curatorial decisions would apply to determining which is the most appropriate for digitisation, either the master production copy, or the original camera tapes.

46 Wikipedia, *Type A videotape*, https://en.wikipedia.org/wiki/Type_A_videotape, accessed 9 December 2017.

Where there is no curatorial path or clear provenance to determine the most original recording, the replay quality inherent in the type A devices will most likely mean that, all things being equal, the duplicate will exhibit visual characteristics that are inferior to the original, e.g., degraded image quality, loss of tracking, and the like. However, the type A machines also had inherent compatibility issues, and the artefacts of duplication may well be indistinguishable from the artefacts of poor compatibility between machines. Therefore, when determining the most original recording from technical characteristics, the authors recommend that the tape be played on more than one device and that machine compatibility issues are taken into account.

C.4.2.3 Replay equipment (playback VTRs)

Type A tapes can only be played on type A machines. Though working type A video machines are not common, they were produced in significant numbers and are available in the second hand and collector market. Ampex made around 30 different models over an 11-year period, and Sony produced one, the BVH-1000, which confusingly, was also the model number for their first type C machine.[47]

External time base correctors (TBCs) are a prerequisite in the replay chain. The TBC should not include a dropout compensator unless it is possible to log and record any compensation undertaken. Testing to determine the most effective and suitable TBC should be undertaken in choosing an appropriate device.

Technical monitoring equipment such as waveform monitors and vector scopes are also necessary when replaying type A tapes. This equipment is needed to calibrate luma and chroma signals and can be used to view sync and burst signals, and check for vertical interval information.

Professional calibrated CRT monitors are also useful for monitoring the output from the VTR, as they have under scan capabilities, and reproduce the composite image output in its original analogue format. This is especially useful when determining the difference between a recorded artefact, and an artefact generated on playback.

Later type A machines had much improved replay characteristics, and they will generally track a well-recorded tape better than earlier machines. However, the compatibility issues associated with the earlier models means that some tapes may well play better with earlier machines. When replaying type A tapes it is desirable to have a choice of machines to replay the tapes.

C.4.2.4 Recording formats

The earliest type A machines dated from 1965 and recorded and played only in a black and white format with a resolution of 300 lines. In 1968, a new type A VTR with an optional heterodyne colour system came on the market, able to record both low-band and high-band colour. The machine decoded the subcarrier to provide colour on playback using an adapter. In other words, it was composite in form, though being colour-under, it is better described as *modified composite*.

Machines were also made with features that suited specific markets, such as medicine. During the lifespan of the format, Ampex introduced various modifications and improvements to those later models. PAL (Phase Alternating Line) encoding was introduced later in this period in response to the standardisation of the European market and to accommodate 50Hz mains.

47 Wikipedia, *Type A videotape*, heading "Some Ampex Type A Models," https://en.wikipedia.org/wiki/Type_A_videotape - Some_Ampex_Type_A_Models, accessed 9 December 2017. See also Weiner: 2011.

C.4.2.5 Sound tracks

The first-generation type A machines recorded a mono audio track using a fixed head (longitudinally) on the lower edge of the tape (a control track was recorded on the upper edge). The linear tape speed was 9.6 ips. The eventual type A specification called for two audio tracks, though by the time of its implementation the industry was changing formats. The audio and control tracks were recorded slightly before the video in the tape path. Audio quality was not exceptional, a typical specification being 50Hz–12kHz +/- 4dB, 42dB SNR and flutter 0.15 percent RMS (Ampex: 1966).

C.4.2.6 Equipment maintenance

Maintaining the type A VTR is critical to achieving the best performance and playback reproduction. An unmaintained or poorly maintained machine can easily damage tapes, and inexpert maintenance can damage the rare type A machines. Thus the VTRs themselves must be carefully maintained to preserve their working life for as long as possible. While many maintenance tasks are relatively simple to an individual with general technical competence, there is always a risk that poorly administered maintenance procedures can damage equipment. It is incumbent on anyone intending to undertake maintenance tasks that they be aware of their own abilities, not exceed those limits, and seek advice or employ those with the necessary technical and specific knowledge to undertake any tasks that might present complexities.

Cleaning type A VTRs is an integral part of the on-going maintenance process. As older tapes shed oxide and clog the heads, regular cleaning is a regular necessity. Cleaning tapes are neither appropriate nor available for this type of machine so manual cleaning of the tape path and video heads is required.

Before proceeding, ensure the machine has been disconnected from the power. Remove covers, panels or drum guards that impede access to the head drum. Clean the heads with either a chamois or lint free tissue moistened with isopropyl or other approved head-cleaning product. Clean the heads by rotating them and lightly pressing the cloth against the head drum. Clean the heads until the tissue is not wiping off any oxide. Never move the cloth vertically up or down as this can damage the heads.

The heads in the rotating drum and the fixed audio and control track heads should be regularly demagnetised using a good quality demagnetiser. Attention should be paid to the process of demagnetisation to ensure that the demagnetiser is removed from the heads while still switched on, to ensure

C.4.2.7 Equipment alignment

In most type A VTRs, the head tip protrusion is adjustable via screws in the head drum. The amount of protrusion is specified in the manuals and is generally measured using a jig with a small indentation. The operations manual of the particular machine will provide information on distinguishing the locking screws from the adjustment screws for the spring-loaded heads.

The azimuth of the fixed audio heads should be adjusted to gain maximum high frequency response providing the machine has that adjustment capability.

The best sources of information on VTR setup, adjustments, and alignment of type A machines are maintenance manuals and other legacy guidelines.[48]

48 Digitised copies of historical documentation can often be found from third-party websites, e.g., at LabGuy's World, http://www.labguysworld.com/, accessed 9 December 2017.

C.4.3 Type B

C.4.3.1 C.4.3.1 Introduction

Bosch Fernseh launched the forerunner to type B, the BCN 1-inch format, in 1975.[49] Improvements in magnetics, tape quality, head manufacture, and signal processing technology meant that it was possible to manufacture a machine whose performance rivalled the 2-inch machines, of which their own machines, the IVC-9000, was one of the last. These new machines were much smaller, less expensive, and the tape and storage costs significantly lower. Like much development of the time, standards followed after; and between 1977 and 1978 the SMPTE Helical Recording Subcommittee settled on a specification for *One-Inch Type B Helical Videotape Recording*.[50]

Type B design was, according to commentators, a hybrid between helical and quad recording (Camras: 1988, p. 474). The small diameter head drum, 50.3mm compared to the larger type A and C head drum, used two video heads separated by 180 degrees. The head drum also included two erase heads at 90 degrees to the video record heads. An extra head for the control track was fixed to the head drum guide, close to the wheel it controls. The video tracks were recorded at a relatively steep angle of 14.288 degrees resulting in shorter tracks and necessitating segmenting the picture field. Type B used five tracks for NTSC and six tracks for PAL encoding of each picture field. The drum rotated at 9000 RPM, resulting in high-density recordings and the first-generation type B machines were capable of recording 96-minute reels.

The small head drum diameter and high-speed rotation are also largely responsible for the type B's higher quality performance. The captured bandwidth was higher than type C, recording with a bandwidth of 5.5 MHz that resulted in superior picture quality. However, the small drum and steeper track angle meant that type B machines could not natively handle still step frame/slow-motion without an additional expensive digital frame store with an analogue time base corrector. Later models like the BCN51 included these additional functionalities.

The tape contacted the head drum in an *omega wrap*, so called because the tape path resembles the Greek letter omega. Rapid switching shifted between the two heads across the gap that occurs as a result of the 190 degrees omega wrap ensured constant tape reading from one of the two 180 degrees spaced heads. This meant that, unlike type A recordings with the gap where the vertical interval should be, type B (and type C) recordings had the signal continuity needed for broadcast settings.

There were two audio tracks for sound and a third audio track that was used for linear time code (LTC). The LTC included an additional 32 bits that were available as user bits for metadata such as date, tape duration or tape number.

The type B format became the broadcast standard machine in continental Europe. In 1984, the type B PAL format was adopted as the EBU European standard for video (Abramson: 2003, p. 205). In the US, machines were made for the military for a short time during the 1970s. Bosch also launched a long play model capable of recording 2 hours, making it possible to handle a full feature film on one tape. Random-access cart machines and portable-cart versions were also marketed.

49 A thorough description of the Bosch BCN B format is provided on the German language page "Das BOSCH BCN B-Format," presented by the Deutsches Fernsehmuseum Wiesbaden, http://www.fernseh-museum.info/das-bosch-bcn-b-format.html, accessed 10 December 2017.

50 "Specifications Drafted for One-Inch Type B Helical Video Tape Recording Standards," *SMPTE Journal*, Vol. 86, November 1977, p. 842, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7241698, accessed 9 December 2017.

C.4.3.2 Selection of best copy

The manufacturers claimed that 1-inch type B recordings could be copied up to 7 generations, and still retain broadcast quality (Camras: 1988, p. 475). It was this quality that led to the format's extensive use for broadcast mastering and any tape of any generation is likely to contain mastered material, if not original recordings. However, the format's long working life means that original news or field recording may have been acquired on film, U-matic, portable 1-inch type B machines, or early generation broadcast quality Betacam cassette formats. In addition, in the production environment, it is likely that the master tapes have been duplicated to mitigate the risk of loss or damage. In consequence, careful selection is important.

Aside from the curatorial decision about whether the master or the original footage, or indeed both, are the target of preservation, the technical determinations of which is the most original copy or best quality copy is a critical concern. Understanding the provenance of the individual recordings will help to distinguish the hierarchy that created them, however, where that does not exist technicians can make assessments of which tapes exhibit the best quality. To determine the difference between master and a dubbed copy a practitioner may distinguish between them by analysing the video and audio replay signal. Dubs that are an inferior representation of the original could present errors, such as tracking playback artefacts, burnt in time code (BITC), or poorly calibrated distorted or low audio levels.

Another determination of higher quality copies is generation loss. Softness of the video image is a quick way to determine obvious generation loss between 1-inch reels containing identical material. In the analogue audio signal, generation loss will present with reduced frequency range and increased noise.

If visual and audio comparison is not obvious through critical visual and audio monitoring, then vector scopes and waveforms can be utilised to observe increased levels of noise to determine the best copy.

C.4.3.3 Replay equipment (playback VTRs)

C.4.3.3.1 VTRs and time base correctors

Type B was a long-lived, popular format, and many VTRs were sold in continental Europe. Since they were largely superseded in the 1990s, however, they have become relatively rare. They are sometimes available on the second-hand market, although buyers should anticipate the need for expert maintenance in order to optimise their performance and meet the original specifications.

Most of the type B machines have an RF signal accessible at the back panel, which is valuable in playback. Time base correctors (TBCs) are a prerequisite in the replay chain and were a part of the original machines. TBCs improve the replay quality by correcting the time base jitter caused by mechanical and electrical tolerances in tapes and machines. Early TBCs use delay lines to store signal, though later technologies are more likely to use digital storage.

C.4.3.3.2 Dropout compensation

Dropouts are typically a gap in a single horizontal line of picture, generally defined by engineers as a decrease in the output signal by more than 12dB for more than 5μs (microseconds).

Dropout compensators (DOCs) are tools that detect the gaps and fill them with a "near neighbour" video segment to produce an output video signal that is dropout-free (Busby, Trytko, and Wagner: 1986). DOCs are an integral part of the broadcast replay chain and ensure that the signal continuity meets broadcast requirements. In systems like the ones being described here, dropout compensation is triggered by a loss of RF signal and consists of substituting a video signal from the nearest scan line that has the same encoding structure (Dhake: 1999).

Dropout compensation presents a dilemma to the video archivist. On the one hand, media archivists adhere to the principle that the content of a tape should be retained without change in a digital *preservation* file, i.e., as an uncorrected transfer. Corrective improvements, according to this principle, ought only be applied to subsidiary copies, an action that is sometimes called *restoration*. On the other hand, however, the TBC and DOC are located at the last point in the playback chain where the RF signal is available to objectively indicate where a loss of signal is a genuine dropout. That is, *this* is the time and place in the digitising process where dropout compensation can be effectively accomplished.

It is also the case that most VTRs for type B and C recordings integrate time base correction and features such as DOC; they are an automatic part of the signal chain. The BCN51, for example, comes with Dropout Velocity Compensator, Time Base Corrector, and Stabilising Amp. Thus, there is no way to prevent the corrections from being made and, in "high policy" terms, some restoration is inevitably part of the preservation transfer.

For these reasons, the IASA-TC 06 authors recommend that dropout compensation be carried out when digitising and, if at all possible, that the process is documented as a part of preservation metadata. Some TBCs may be able to log any compensation undertaken or, if that is not possible, the archive's metadata should note that a given transfer was carried out using systems that provide dropout compensation.

C.4.3.3.3 Waveform monitors, vectorscopes, and calibrated monitors

Technical monitoring equipment such as waveform monitors and vectorscopes are also critical when replaying type B tapes. The BCN 51 and 52 comes with these tools integrated. This equipment is needed to calibrate luma and chroma signals, to view sync and burst signals, and to check for vertical interval information.

Professional calibrated CRT monitors are also useful for monitoring the output from the VTR, as they have under scan capabilities, and reproduce the composite image output in its original analogue format. This is especially useful when determining the difference between a recorded artefact, and an artefact generated on playback.

C.4.3.4 Recording formats

Bosch also launched a Long Play model capable of recording two hours, making it possible to handle a full feature film on one tape, and even special machines capable of recording 4 hours were made. Specially adapted machines, such as the Bell and Howell's modified BCNs, were also used for mass duplication of VHS cassettes, as well as instrumentation recording for NASA and the Space Shuttle project. Random-access cart machines and portable-cart versions were also marketed. Models from the BCN 51 onwards included optional hardware that enabled slow motion and visible shuttle, to make it more competitive with the type C, which could do this natively.[51]

51 Wikipedia, *Type B videotape*, heading "Models introduced," https://en.wikipedia.org/wiki/Type_B_videotape#Models_introduced, accessed 9 December 2017.

Type B, as discussed, breaks up each field in several parallel tracks (segmented): 5 segments are recorded for NTSC and 6 segments for PAL (Camras: 1988, p. 475).

C.4.3.5 Equipment maintenance

Maintaining the type B VTR is critical to achieving the best performance and playback reproduction. This VTR is even more highly specialised than its predecessors, requiring knowledge and expertise to undertake most maintenance tasks. However, unlike the type A machine, repair and maintenance is still available at the original plant in Weiterstadt, Germany.

While many maintenance tasks are relatively simple to an individual with general technical competence, there is always a risk that poorly administered maintenance procedures can damage equipment. It is incumbent on anyone intending to undertake maintenance tasks that they be aware of their own abilities, not exceed those limits, and seek advice or employ those with the necessary technical and specific knowledge to undertake any tasks that might present complexities.

The type B machine was very popular and used VTRs are still available. This popularity means that a large number of tapes were recorded and now need to be digitised for preservation. Thus, these VTRs are an integral part of maintaining access to the tapes whose content we are aiming to preserve, and they must be carefully maintained to preserve their working life for as long as possible. While many maintenance tasks are relatively simple for an individual with general technical competence, there is always a risk that poorly administered maintenance procedures can damage equipment. It is incumbent on anyone intending to undertake maintenance tasks that they be aware of their own abilities, not exceed those limits, and seek advice or employ those with the necessary technical and specific knowledge to undertake any tasks that might present complexities.

As the tapes to be digitised continue to age, and the amount of shedding increases, we recommend cleaning the heads and path before every tape is loaded. The owner's manual for the Bosch type B VTR states that all heads and tape guiding elements should be cleaned with a lint-free cloth. It also notes that the video heads, the audio head stacks, and the control track head in the scanner drum demand special care, providing these directions, "When cleaning the video heads, the scanner can be held and rotated with [the supplied] 2-mm hex screwdriver. Gently press the cloth against the scanner drum and rotate the disk several times. Also clean the scanner drum and the control track head" (Bosch: n.d., p. 41).

C.4.3.6 Equipment alignment

In order to gain best replay, the VTR needs to be aligned for every reel by adjusting tracking using RF meters, video, and audio signals. Some later machines, such as the BCN 51 also have an "Optimise Mode". This feature ensures the best possible signal by optimising the head currents after changing the scanner system, using different tape types or after prolonged VTR Operation. Access to waveform monitors, vectorscopes, and oscilloscopes are required for standard video and audio alignment. Since type B recordings present segmented fields, exact alignment is of utmost importance to avoid what is called *banding* (visible bands across the picture).

C.4.4 Type C

C.4.4.1 Introduction

During the mid-1970s, video equipment manufacturers were competing to find a lower cost replacement for the broadcast standard 2-inch quad recorder. At the same time that Bosch Fernseh were developing the BCN 1-inch (later standardised as type B), Ampex and Sony had formed an alliance to develop a 1-inch helical scan, non-segmented video recording device. In 1978, the SMPTE Helical Recording Subcommittee established the type C standard and published the specification.[52]

The tape path was an omega wrap, maintaining head contact over 344 degrees (Sony: n.d.). It overcame the major disadvantage of type A by using a second narrow track head set at 180 degrees to the main head on the head drum to fill the gap in the signal as the head crossed the tape gap. This was termed the 1½ (one and one-half) head system and is a defining characteristic of the type C format (Camras: 1988, p. 465). The track angle was a low 2 degrees, 34 minutes which, when combined with the complete video field (non-segmented), allowed for native shuttle mode, slow motion and still frame replay, all of which became expected features required by the broadcast industry. The tracking error inherent in such an approach was compensated for by a server-controlled, piezoelectric tracking device, which could deflect the head the small, but critical, amount necessary to maintain tracking. Separate stationary heads record the audio and time code tracks.

Large size reels accommodated 90 minutes of recording time. The format supports three audio tracks: two for stereo sound with the third supporting a cue track for linear time code, as well as VITC (vertical interval time code).

An important feature in type C development is servo control of the tape tension. The servo controls the tape tension or tape skew to the extent that it can stretch the tape enough to compensate for dimensional changes due to humidity or temperature. The very tight tolerances, narrow track widths, and the density of information make this a necessity. This was not achievable only a few years before the development of type C, but "the critical dimensions and balancing that were so difficult at first have been brought under control by experience and precision fixtures so that head angles are routinely set within seconds of arc (1/3600 of a degree)"[53]. This highlights the difficulty in maintaining precision equipment without the specialist tools and industry support that is no longer available with an obsolete technology.

Unique to the analogue format was an in-built functionality and output processing which made it possible to simultaneously monitor and adjust RF, audio, and video signals for optimum playback. This suits the mass digitisation workflow now, as it supported video production in the past.

52 "Draft American National Standard: Basic System and Transport Geometry Parameters for 1-in Type C Helical-Scan Video Tape Recording, Proposed SMPTE Recommended Practice: Tracking-Control Record for 1-in Type C Helical-Scan Video Tape Recording, and Proposed SMPTE Recommended Practice: Video Record Parameters for 1-in Type C Helical-Scan Video Tape Recording," *SMPTE Journal*, March 1978, Vol. 87, pp. 163-168, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7241495, accessed 9 December 2017.

53 "Draft American National Standard: Basic System and Transport Geometry Parameters for 1-in Type C Helical-Scan Video Tape Recording, Proposed SMPTE Recommended Practice: Tracking-Control Record for 1-in Type C Helical-Scan Video Tape Recording, and Proposed SMPTE Recommended Practice: Video Record Parameters for 1-in Type C Helical-Scan Video Tape Recording," *SMPTE Journal*, March 1978, Vol. 87, pp. 163-168, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7241495, accessed 9 December 2017.

Type C VTRs were modular with many different playback, editing, monitoring, and signal processing options. Broadcast engineers sometimes modified their VTRs to suit the needs of the television station. Some decks supported 4 channels of audio, playback of reels large enough to hold three hours of recording, dynamic tracking, vacuum assisted lace up, and portability.

In many respects, the type C was a step ahead of the competition in terms of functions it provided, offering what might be called "disruptive" capabilities when compared to its main competitor. Although the picture quality was slightly inferior to the type B, it nonetheless became the industry standard in video production all over the world. Even in continental Europe, from the mid-1980s, the type C format became established in video production facilities outside the broadcast companies and could be found amongst commercial video providers.

C.4.4.2 Selection of best copy

The type C format was the standard television program master format for at least two decades. It was used extensively in all fields of video capture and production, and the high-quality output, and low duplication losses, encouraged users of the technology to copy material as part of the production processes. It is likely, therefore, perhaps even more so than type B, that there will be more than one copy of content across generations. In addition, the long life of the format and the almost complete market penetration for a long period of time indicates that the original video may have been captured on film, U-matic, portable 1-inch type C machines, or earlier generation broadcast quality Betacam cassette formats.

The first decisions in selection of best copy are curatorial, requiring a practitioner to determine what is in scope for copying and preservation. Once it is known whether the master, as representing the final Work, or the original footage, presumably for the subject, (or both) has been selected, the decision about which copy contains the most complete and highest quality information becomes the next critical step.

From the standpoint of good archival practice, the accepted argument would be that the earliest, or most original copy would contain the most complete information, and it is the case that this mostly holds true for 1-inch type C. During production it is possible, indeed likely, that second copies of the same format were made of some material to avert the risk of loss. If such copies exist, and presuming they are of similar age and format, the labelling and associated data may provide clues as to the most original. If not, then an informed subjective decision needs to be made drawing on the technical characteristics of the replay as well as the perceived quality of the signal. If doubts exist, copy both.

Degradation of the recordings by the passage of time may cause the tapes to produce incomplete information when played back, with loss of RF being a primary example. In such circumstances, it is worth checking later generation copies, possibly of a different format. As type C was so widely adopted and used for important material, it is possible that proactive archives have already transferred the content to another master format in order to keep pace with technological changes and storage demands. Where the original and the later copies both exist, the same subjective decision-making processes apply.

C.4.4.3 Replay equipment (playback VTRs)

C.4.4.3.1 VTRs and time base correctors

Type C was the most long-lived and popular format in the 1-inch helical scan class, with type C VTRs sold in significant quantities worldwide. Training in their care and maintenance generally accompanied this highly developed distribution chain. Sony and Ampex were the primary manufacturers of the format, but by no means the only ones. Type C VTRs were also manufactured by NEC, Philips, RCA, 3M, and Nagra.[54]

Though type C machines were largely superseded in the 1990s, the size of the market and the large commitment to that technology meant that there were many machines manufactured. They were the most reliable, and many survived. Nonetheless, they are in great demand because this popularity meant that many tapes were produced. Machines do appear on the second-hand market, but there is strong competition for their purchase.

Most type C machines have an RF signal output accessible at the back panel, which is valuable in playback. External time base correctors (TBCs) are a prerequisite in the replay chain and were a part of the original machines. TBCs improve the replay quality by correcting the time base jitter caused by mechanical and electrical tolerances in tapes and machines. Early TBCs use delay lines to store signal, though later technologies are more likely to use digital storage such as the Sony BVT-2000.

C.4.4.3.2 Dropout compensation

See C.4.3.3.2.

C.4.4.3.3 Waveform monitors, vectorscopes, and calibrated monitors

Technical monitoring equipment such as waveform monitors and vectorscopes are also critical when replaying type C tapes. The BCN 51 and 52 comes with these tools integrated. This equipment is needed to calibrate luma and chroma signals, to view sync and burst signals, and to check for vertical interval information.

Professional calibrated CRT monitors are also useful for monitoring the output from the VTR, as they have under scan capabilities, and reproduce the composite image output in its original analogue format. This is especially useful when determining the difference between a recorded artefact, and an artefact generated on playback.

The small, lightweight "spot reels" caused problems on some of the machines and required a weight attachment to mimic the mass of the larger reels. The Scotch 3M video spot reel box states:

> Some VTRs require a weight attachment for lightweight reels when used in 'editing' type applications. The Scotch Brand VRB-1-150 Video Spot Reel has been designed for use in conjunction with the Scotch Brand VWB-150 Inertia Balance Weight in these applications. This weight attachment is precision made of stainless steel and cannot be magnetised. It fits simply onto the front of the reel, is locked in place by the VTR spindle clamp during operation, and is easily removed when desired.[55]

Some operators have created their own carefully balanced weight from stainless steel or similar.

54 Wikipedia, *Type C videotape*, includes list of machines, https://en.wikipedia.org/wiki/Type_C_videotape, accessed 10 December 2017.

55 Text from the box for the Scotch 3M VRB-1-150 Video Spot Reel.

C.4.4.4 Recording formats

RCA introduced a new transport design that would handle two-hour reels in 1980 at NAB, and Ampex and Sony followed suit in the 1982 NAB show (Carpenter: 1983). Later in the same year the so-called "third generation" of type C machines were introduced at IBC. These included up to three-hour reels and had significant advances in tape handling and field sensing to enable rapid tracking, but were still the same format (Carpenter: 1983). Specific machines are required for the playback of the very large reels associated with three-hour playback, such as BVH-2830.

The type C head spins at 3,600 RPM (60Hz) for NTSC and at 3000 RPM (50Hz) for PAL (Camras: 1988, p. 472).

C.4.4.5 Equipment maintenance

Maintaining the type C VTR is critical to achieving the best performance and playback reproduction. The type C machine is complex and precise, and it requires a high level of expertise to maintain, repair and, if necessary, modify. The large number of type C tapes in various archives and broadcast libraries, together with the finite availability of VTRs, signals the importance of these VTRs to the provision of access to important historical content. While many maintenance tasks are relatively simple to an individual with general technical competence, there is always a risk that poorly administered maintenance procedures can damage equipment. It is incumbent on anyone intending to undertake maintenance tasks that they be aware of their own abilities, not exceed those limits, and seek advice or employ those with the necessary technical and specific knowledge to undertake any tasks that might present complexities.

The type C was widely used and, when the VTRs were being sold and distributed, they were accompanied by highly developed training and maintenance support. Although support for these VTRs has long ceased, some level of expertise can still be found amongst the now rapidly aging technicians who received that training. Parts for these machines are more difficult to source, and even non-working machines are valuable for parts.

As the tapes to be digitised continue to age, and the amount of shedding increases, we recommend cleaning the heads and path before every tape is loaded. As outlined for type B tapes, heads and tape guiding elements should be cleaned with a lint-free cloth. The video heads, the audio head stacks, and the control track head in the scanner drum demand special care and the lint free cloth should be held steady as the head is rotated.

C.4.4.6 Equipment alignment

The alignment of the machine is necessary to obtain the optimum replay. Before commencing replay, the VTR needs to be aligned for every reel by adjusting tracking using RF meters, video signals, and audio signals. Later machines have video levels, including luma, black levels, chroma gain, chroma phase/shift, audio levels, RF tracking, and time code selection. These should always be adjusted on the VTR or TBC as it will enable optimum replay of the signal. A waveform monitor, vectorscope, audio meters, and speakers are required on the source machine output, rather than the destination or processed digital signal, such as SDI. We recommend that only a person with good knowledge and experience adjust additional settings on the VTR. Record inhibit should be switched on permanently to avoid accidental erasure.

C.4.4.7 Calibration tapes and test media

The availability of alignment tapes for the 1-inch VTRs is a critical problem. At the time the machines were being manufactured, one specialist stressed the value of alignment tapes:

> The complexity and precision required for adjusting individual recorders to allow interchangeable records would be almost impossible for users in the field were it not for standard tapes that have been recorded to exacting specifications. These tapes are used on machines to set playback. An adjustment routine is then followed to optimise, among other things, the tape tension, synchronisation, output, colour, and audio (Camras: 1988, p. 472).

Even used alignment tapes are of significant value. It is also the case that many tests can be undertaken with locally created tapes and alignment technology, providing the technician has a thorough understanding of the difference between a properly manufactured alignment tape, and the small-scale solutions developed to overcome their absence. In the absence of an engineered calibration tape, practitioners can record, on a recently aligned and certified machine, a few minutes of 75 percent EBU colour bars, and a series of tones at 100Hz, 1kHz, 10kHz, and 15kHz. In section D.1.3.1.4.4.4, this category of test tape is termed *house-made (or third party) VTR alignment and calibration tape*. Playing this house-made alignment and calibration tape in transfer situations can assist technical staff to trouble shoot the process when, for example, an operator is faced with a troublesome tape in replay. The self-manufactured test tape can help to determine whether the tape or the machine is at fault.

C.4.5 Cleaning and restoring 1-inch tape formats

C.4.5.1 Tape cleaning and cleaning machines

As with all reel-to-reel magnetic tape formats, an inspection of dirt, edge damage, irregular tape pack, and wind needs to be done. Surface cleaning and rewinding may be necessary to get an optimal transfer.

Cleaning machines for 1-inch formats are available, and cleaning is a prerequisite for almost all of the later generation tapes. Tapes for type B and C tapes are all from the mid to late 1970s and belong to the period of manufacture that is associated with binder degradation. Thus, these tapes are likely to cause the tape heads to clog with residue and make replay less than ideal. Type A tapes may, or may not, suffer from binder degradation to quite the same extent as the later tapes. Nonetheless, cleaning is recommended.

Cleaning machines were originally designed to recycle videotapes. Today, their main use is for collection cleaning and refreshing prior to digitisation. Cleaners include magnetic detection for head clogging and oxide variations, and opto-electronic defect detection to detect physical damage or deterioration to the tape itself. Cleaning systems employ tissue rollers to catch excess tape shedding and/or burnishing blades to skin the surface of contaminants and residue to ensure best reproduction. When cleaning a reel on a machine with burnishing blades it is critical to check the quality of the blades beforehand to avoid damage to the tape.

RTI, the cleaning machine manufacturer, recommends that the very sharp sapphire burnishing posts are carefully checked with a business or credit card to locate any rough or nicked edges which could damage the tape:

> Periodically run the edge of a business card along the operating edge of the sapphires to insure their smoothness before running videotape on the machine. A nicked or rough edge of a burnishing blade would cause the card to 'drag' as any nicks are encountered. Additionally, a ticking sound may be noted as the card traverses any nicks. Alternately, a stylus microscope or illuminated magnifier may be used to check the blades visually (RTI: 1986).

As discussed in this section, type B are wound with the oxide out, type C are wound with the oxide in, and type A will most likely be oxide in on the supply reel and oxide out on the take-up reel. Therefore, it is wise to check the cleaning machine and the tape wind before cleaning the tape. Some machines have switchable tape paths to suit each format's particular wind.

If the tapes show sign of softening binder, tape baking can temporarily increase the chances of a successful playback, by increasing the temperature to the tape which firms up the tape binder by restoring some of the adhesive and cohesive properties of the binder.

Baking tapes should be carried out in a professional scientific oven with a constant temperature of 50 degrees C. Replaying tapes warm can greatly improve the chances of a successful playback for tapes showing signs of hydrolysis. For some stubborn tapes, the tape may be baked "tail out" for a period of time, re-spooled and baked "head out" for the same period, in order to ensure best replay.

C.4.5.2 Correction for sub-optimal transfers caused by misaligned equipment

For reels recorded on misaligned machines, special modification may be required. In some extreme cases machines might need to be aligned out of specification to allow for proper playback. This should be carried out by an experienced engineer as it could jeopardise quality reproduction of many other recordings.

C.4.6 Time code

Time code carriage on 1-inch helical-scan videotapes is too varied and complex to address in a comprehensive way in this guideline. To generalize, types B and C carry longitudinal (aka linear) time code (LTC) on a track in parallel with the formats' two audio tracks. The video expert Tim Stoffel reports that the type A specification provides for an "address track"[56].

C.4.7 Distinguishing 1-inch tape types

Soon after work was completed on the type A, B, and C standards, SMPTE put a call out in its Journal under the title of "Preliminary Exchange of Experimental Interchange Tapes for Types B and C Helical Videotape Recorders" (Fibush: 1978). Presumably this committee was testing the interchange between tapes of the same type, because types A, B ,and C tapes are not compatible except on tape machines of the same type as they were recorded, i.e., if one type is played on a VTR designed for one of the other types, the results may be indistinguishable from the outcome of playing a blank tape. No machines were ever produced that allowed switching between the types.

56 See Tim Stoffel's extremely helpful compilation of information at under the heading "Formats using 1 inch wide tape" (scroll to *type A*), http://www.lionlamb.us/quad/format.html#1instd, accessed 10 December 2017. This presentation is one segment of the *Videotape formats* webpage (Stoffel: n.d. [b]).

The incompatibility of types A, B, and C is important, given that all three formats use the same underlying media, i.e., 1-inch open-reel videotape. On the shelf, type A, B, and C videotapes can look very similar. The 1977 SMPTE journal article that announced the completion of work on the type B and C standards also announced the establishment of a new working group to develop the "American National Standard Dimensions of One-Inch Video Magnetic Tape" and "American National Standard Dimensions of One-Inch Video Magnetic Tape Reels" (Alden: 1977).

To distinguish between the ways the tapes were recorded requires a logical approach and the use of all the related data that may inform the decision.

Tapes recorded before 1975 are likely to be type A, but may not be labelled such as the specification and naming of type A was developed retrospectively. The tape brand is likely to be Ampex. It may be spooled either oxide out or oxide in depending on whether the tape was recorded oxide in or out.

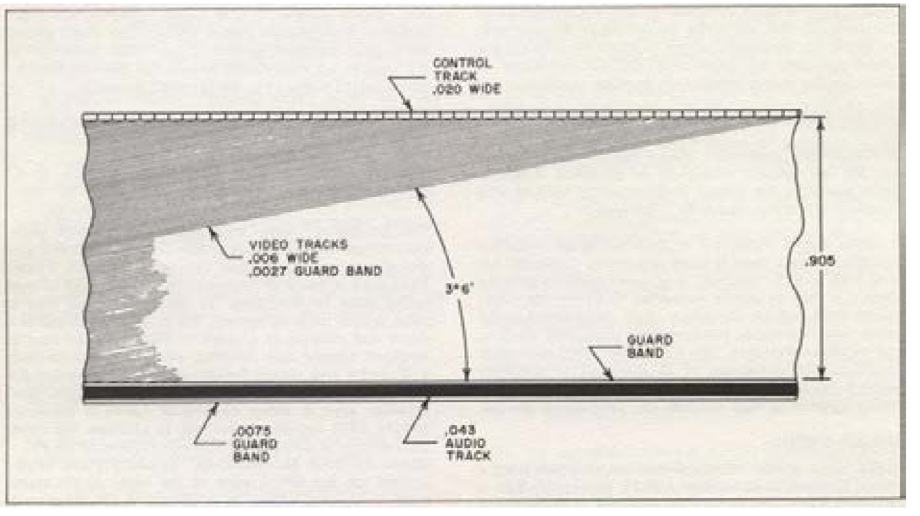
Tape B is primarily a European format but can be found in Asian and South East Asian archives and broadcast facilities. It should be stored oxide out.

Type C is the most common, and should be found stored oxide in.

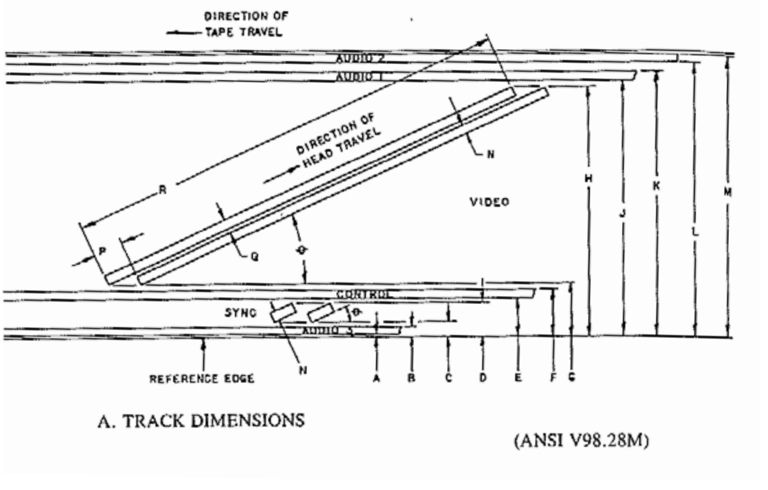
If a tape is played on the wrong machine (if the type B tape has been wound oxide in), the picture information will be missing entirely but it may be possible to hear the audio tracks, though possibly in the wrong channels. Identifying the channels that carry the audio may help identify the tape's format.

The following diagrams show the recording layout of the 1-inch videotapes. Engineers have long used a magnetic substance in suspension to "develop out" the magnetic patterns on the tape. The suspension calls for "an aqueous suspension of aggregates (clusters) of iron oxide particles of 0.007µm [micrometre] in diameter" (Rijckaert, 1982, p. 129). This is very useful for checking mechanical alignment and the effectiveness of the operation of the servo controllers in 1-inch machines. It would also clearly show whether the tape was type A, B, or C by showing the angle of recording or the layout of the tracks. When editing quad 2-inch recordings in the early days, the magnetic suspension showed the placement of the tracks and permitted an operator to edit with a razor blade without losing the integrity of the control and video tracks.

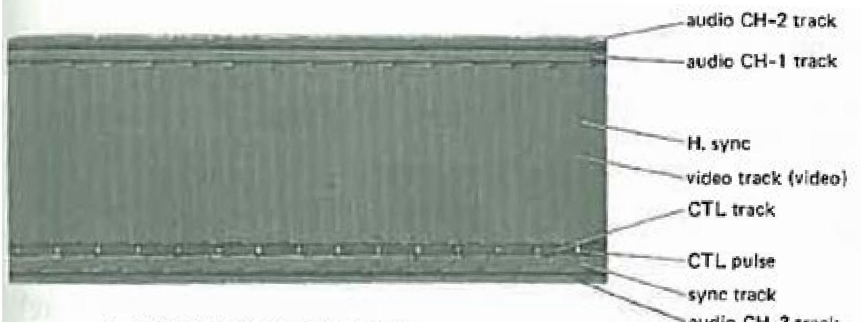
C.4 Figure 1. 1-inch type A track configuration



The track configuration for 1-inch type A tapes (Ampex: 1966, p. 2).



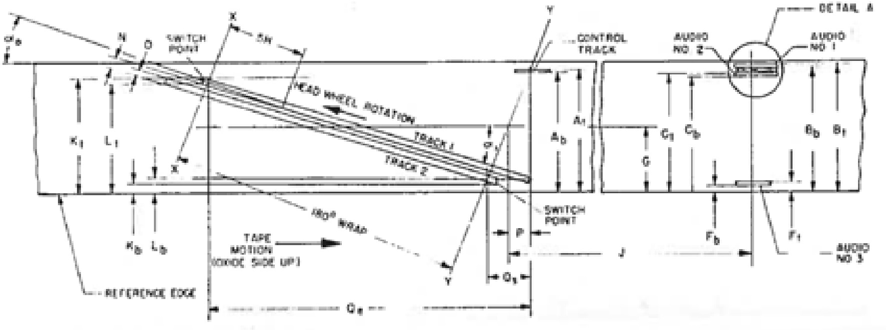
	Dimensions	Millimeters Minimum	Maximum
A	Audio 3 lower edge	0.050	0.150
B	Audio 3 upper edge	0.825	0.975
C	Sync track lower edge	1.385	1.445
D	Sync track upper edge	2.680	2.740
E	Control track lower edge	2.870	3.130
F	Control track upper edge	3.430	3.770
G	Video track lower edge	3.870	3.910
H	Video track upper edge	22.385	22.445
J	Audio 1 lower edge	22.770	22.830
K	Audio 1 upper edge	23.525	23.675
L	Audio 2 lower edge	24.325	24.475
M	Audio 2 upper edge	25.150	25.250
N	Video and sync track width	0.128	0.132
P	Video offset	4.067 ref (2.5H)	
Q	Video track pitch	0.1823 ref	
R	Video track length	410.764 ref (252.5H)	
S	Control track head distance	101.8	102.2
T	Vertical position, odd field	1.220 (0.75H)	2.030 (1.25H)
U	Vertical position, even field	2.030 (1.25H)	2.850 (1.75H)
V	Sync track length	25.620 (15.75H)	26.420 (16.25H)
W	Vertical position, odd sync field	22.360 (13.75H)	23.170 (14.25H)
X	Vertical position, even sync field	23.170 (14.25H)	23.980 (14.75H)
Y	Vertical head offset	1.529 ref	
Z	Horizontal head offset	35.350 ref	
θ	Track angle	2°34′ ref	



B. DEVELOPED-OUT PATTERN

(Courtesy SONY; BVH-1100 MANUAL)

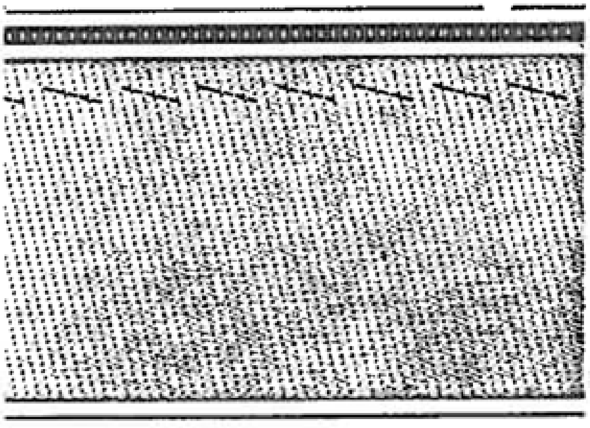
C.4 Figure 2. 1-inch type C track configuration



A. TRACK DIMENSIONS

ANSI V98.30M

	Dimensions	Millimeters Minimum	Maximum
A_b	Control track bottom edge	23.54	23.64
A_t	Control track top edge	23.94	24.04
B_b	Audio 1 track bottom edge	24.34	24.44
B_t	Audio 1 track top edge	25.14	25.24
C_b	Audio 2 track bottom edge	22.34	22.44
C_t	Audio 2 track top edge	23.14	23.24
F_b	Audio 3 track bottom edge	0.16	0.24
F_t	Audio 3 track top edge	0.96	1.04
G	Center of video tape	12.70 ref	
J	Position of audio heads	232.2	232.8
K_b	Full video width bottom edge	1.18	1.18
K_t	Full video width top edge	22.19	22.19
L_b	Video width (180°) bottom edge	1.82 ref	
L_t	Video width (180°) top edge	21.55 ref	
N	Video track pitch	0.200 ref	
O	Video track width	0.156	0.164
P	Position of control track head	2.845	2.875
Q_2	Switch point distance video 2 track	82.096	82.121
Q_1	Switch point distance video 1 track	5.523	5.533
S	Distance between control track head gap and center edit pulse at 180° switch point	0.040 ref	
α_0	Scanning angle (Helix angle)	14.434° ± 10″	
α_1	Video track angle (525/60)	14.288°	



B. DEVELOPED-OUT PATTERN

Bosch Techn Berichte 6(1979)

Type B

C.5 U-MATIC ¾-INCH VIDEOCASSETTES

C.5.1 Introduction

The U-matic format, also known as *¾-inch* due to the tape width, was developed by Sony, Matsushita, and JVC, and released by Sony in 1970 to the market as the first videotape housed in a cassette. Originally intended for the industrial and educational market, broadcasters soon acquired the format, and that uptake led to the addition of professional features, such as time code support, higher quality resolution, and editing capabilities (Martin: 2007).[57]

In the early 1980's, U-matic replaced 16mm film in news acquisition and production, and was integral to production in the broadcast industry right up until the early 1990's. Even though most broadcasters had progressed to Betacam SP by this stage, U-matic was still in use in universities and advertising agencies: it had become a de facto standard. The name U-matic is derived from the U-shaped tape path around the rotary helical video head drum. The tape runs at approximately 93mm/sec, with the supply and take up reels rotating in the opposite direction of each other while in operation. The tape runs from right to left on playback (Sony, 1995).

U-matic was established as a SMPTE standard in 1997, where the format is referred to as *3/4-inch Type E Helical-Scan Cassettes*.[58] The standard's specifications include the dimensions of the videocassettes, which come in large and small sizes. Smaller tapes such as the KSP-S10, or KCS-10XBR series, are designed for portable units and run between 10 and 20 minutes, while larger tapes such as the KCA-10XBR or the KSP-60 series provide running times up to 60 minutes. U-matic VTRs have photocell assemblies that detect the beginnings and the ends of tapes; most tapes have clear leader to allow the detection system to function properly (Sony: 1989).

U-matic is a heterodyne or colour-under system that converts composite video into a reduced-data signal that requires less bandwidth and can be recorded at slower tape speeds. The heterodyne process separates the luma and chroma signals, and then reduces the chroma for recording. Luma is recorded as an FM signal, while chroma is recorded as an AM signal. The down-conversion is reversed for playback, where the chroma signal is remixed with the luma signal to recreate the composite output. This type of colour-under system is also used for VHS, Beta, S-VHS, 8mm, and Hi8mm format. Although efficient in terms of data flow and storage, the process of up and down converting, along with the mixing of luma and chroma in composite delivery, greatly increases noise and artefacts associated with U-matic (and other colour-under) recordings (Sony: 2016).

Colour framing is also a heterodyne feature of U-matic, where every frame is monitored for its colour accuracy using a colour framing servo system.

57 See also "The Format" section of the *U-matic PALsite* (Barnett and Evans: n.d. [b]), http://umatic.palsite.com/format.html, accessed 11 December 2017.

58 SMPTE standard ST 22:1997 (Archived 2010), *Video Recording – 3/4-in Type E Helical Scan – Cassette.*

Another feature of the U-matic system is the dub signal interface, a direct 7-pin connection for what is called *Y-688*. The *Y* stands for *luma* and *688* represents the *688 KHz carrier frequency* for the reduced chroma signal. This 7-pin connector allows the luma and chroma signals to remain separate between playback and record U-matic VTRs when dubbing (copying) a tape. This greatly reduces the artefacts and noise resulting from the use of a composite signal, e.g., dot crawl. However, the dub interface is only available for U-matic VTRs and a limited number of video editing systems, including some time base correctors (TBCs) and non-U-matic VTRs like the PVW-2800 for Betacam SP tapes.[59]

The U-matic format supported three recording modes during its production life, utilising different carrier frequencies and resolutions.

Mode	Resolution	Y Carrier	Chroma Sub-Carrier
SP (Superior Performance)	300 lines	5.6-7.2 MHz	924 kHz
High-band	260 lines	4.8-6.4MHz	924 kHz
Low-band	260 lines	3.8-5.4 MHz	685 kHz

C.5 Table 1. U-matic recording modes. This table summarizes information found in Sony's *Video Cassette Recorder VO-9800P Operating Instructions* (Sony: 1989), and other sources.

Not all U-matic decks are interchangeable between VTRs and cassette tapes, as SP is only supported in later model VTRs such as the VO-9800 series on KSP series U-matic cassette tapes. VTRs that support SP will automatically switch between the systems for playback.

An important factor with VTR format support is that SP or high-band recordings will lose chroma information when played back on a low-band VTR.

Several factors can make it difficult for archives to obtain quality playback of U-matic cassettes:

- VTRs in good working condition with available spare parts are quite rare
- Engineering skills to repair and replace worn parts is diminishing as a trade
- Tapes in this format are aging and deteriorating

C.5.2 Extent of U-matic holdings and urgency of digitising

In George Boston's 2003 UNESCO *Survey of Endangered Audiovisual Carriers*, 41 institutions reported a total of 63,022 U-matic cassettes. Of these, about 21 percent were classed in *good condition*, 42 percent *giving some concern*, and 36 percent *obviously decaying* (Boston: 2003). This last percentage has continued to rise as tapes continue to age.

Technical obsolescence is a key factor in the urgency to digitise U-Matic cassettes. The diminishing worldwide stockpile of machines and parts has placed significant collections at risk of being lost forever. Digitisation must be approached with the intention to playback the videotape for the last time, and the IASA-TC 06 authors say, "Do it once, do it right!"

59 See the "PVW-2800 Features" section of the *Betacam PALsite* (Barnett and Evans: n.d. [a]), http://betacam.palsite.com/pvw2800feat.shtml, accessed 11 December 2017.

C.5.3 Selection of best copy

Along with curatorial selection methods for determining the best copy, there are technical considerations for U-matic that can also be applied to other magnetic media formats. It is not common to find multiple copies of content held on U-matic, however there are some considerations that influence best video selection:

- Availability of compatible replay equipment. Related questions: Is the tape low-band, i.e., compatible with a low-band-only VTR? Is the tape NTSC or PAL?
- Multi-generational recording. Related questions: Is this the original camera tape, or is U-matic a release copy with a 'burnt-in' time code window? Does the content also exist on a higher quality format?

As U-matic was mainly an acquisition or off-line editing format, the content was sometimes mastered into a final production program on 1-inch. Although the raw footage or production elements may be the original, the final master could exist on another format. A decision would need to be made on which is the most appropriate for digitisation, either the master production copy, or the original camera cassettes. It is common to find newsroom stories compiled onto 60 minute tapes.

Check the current storage condition of the cassettes, and if possible trace the storage condition of the life of the collection. This can help decide which copy to digitise if one tape has been stored in a cool, constant low-humidity environment compared to another duplicate with an unknown history.

C.5.4 Cleaning and carrier restoration

C.5.4.1 Physical inspection of the cassette housing

As with other videocassette formats, U-matic cassettes need visual inspection to determine if they require repair treatment before inserting into a cleaning machine, or VTR. Check that the mechanics of the cassette housing are not damaged or broken, e.g., that the tape door hinges have not snapped or become loose. This can be confirmed by opening the door carefully as not to touch the tape. If the tape is not visible then it has either snapped, or the glue that holds the tape and leader has given up and separated. The cassette will need to be disassembled to retrieve the tape, and re-spliced.

Check that there are no labels that are stuck in places that could inhibit the proper function of the cassette. Also remove any sticky residue caused by old labels off the tape using a cloth slightly dampened with soapy water. This residue can contaminate cleaners and VTRs.

Check that the window is not broken or cracked and interfering with normal operation of the cassette mechanisms. Check for any deformity caused by excessive heat. This can create unusual noises when running through the cleaner or VTR.

Gently shake the tape and check for anything rattling inside. This can indicate that the tape has loose or broken parts that could damage the tape or the VTR. If there are loose parts, the cassette will need to be disassembled for inspection and the broken parts will need to be replaced.

Check the pack of the tape through the cassette window to make sure there are no obvious pack problems with the tape, such as excessive edge damage. Binder degradation can also appear as a white powder sitting on the tape pack. Check for any visible signs of mould.

Mould can appear as patterned black, brown, white, or mustard growth. Be particularly careful when handling mouldy tapes as some moulds can be extremely harmful and always wear personal protective equipment (i.e., gloves, eye protection, and face mask). When working with mould, it is preferable to use a ventilation hood to reduce the chance of contamination. Any conservation work undertaken with mould requires the practitioner to exercise extreme care when handling the cassette.

Remove the red tab from the underside of the cassette to prevent accidently recording on the tape. If the cassette is physically damaged, e.g., the cassette is broken, or affected by fire or flood, the tape will need to be removed from the cassette and housed in a replacement cassette shell.

Re-house the tape into a clean cassette shell. Used cleaning cassettes are convenient for this exercise.

Wear gloves while performing the operation.

Cut any labels on the label edge of the cassette along the join with a razor, so the bottom half will freely lift off.

Release the tape door lock and lift the cassette door folder with the cassette upside down on a clean workbench. Hold the door open with an instrument without touching the tape.

Unscrew all the screws located on the underside (usually 5 screws holding the cassette together, with 2 or 3 smaller screws holding the guide posts in place). It can be useful to use the same screws in the same holes, as the hole is the moulded plastic of the shell.

Whilst gently lifting the cassette base, note the tape path and the location of the clear plastic tabs. This will assist in the replacement of the shell.

If the tape is broken, pull out both ends of the tape, enough to lie flat on a splicing block. If a block that supports ¾-inch tape is unavailable, a clean surface will substitute. Cut any amount of badly damaged tape length before splicing the tape. Line both ends of tape up horizontally and vertically to each other, and apply clean film splicing tape to join the splice together. Cut any excess tape off the horizontal edges of the tape so there is no splice tape protruding over the edge of the tape. Then wind the tape back until it is almost taught. Carefully replace the bottom shell noting the tape path through the two guide posts on the left and around the one on the right. The trick is to make sure the clear plastic tabs are sitting on either side of the tape.

Replace screws and now the tape is repaired. Run it through a cleaner making careful attention to the area of repair. If it runs successfully the tape is ready for playback in a VTR.

C.5.4.2 Tape formulation

Particular tape stocks and brands can behave differently on playback than others. Some stock can clog heads more often and be more susceptible to sticky shed syndrome. Problems can also occur with a batch of stock created at a particular time, where the formulation of the tape was slightly different. Before starting a large-scale digitisation project, it is useful to test playback from different brands, and see what issues occur. This data can then be used to prioritise problem tapes for digitisation or to prioritise good quality tapes for a larger success rate. In a table of playback problems encountered by a service provider to INA, 35 percent were AGFA stock, 25 percent were PYRAL, and less than 10 percent were 3M (Addis and Veres: 2007).

As there are many contributing factors including formulation relating to playback problems with an archives U-matic collection, an assessment of the holdings will give a relatively accurate representation of issues that will be encountered.

C.5.4.3 Cleaning

If the tape has passed the first stage of visual inspection or has been repaired, then it is appropriate to clean the U-matic tape in a specialised cleaning machine.

Cleaning machines are critical for U-matic tapes since the tapes are 20 or more years old. It is quite common for U-matic VTR heads to clog during playback, especially with problem coating formulas. Cleaning tapes before playback will greatly increase the success rate of U-matic playback.

Cleaning machines offer varying features. Features like the following will be helpful when processing a set of U-matic videotapes:

- Optical inspection to detect physical problems with the tape (such as a folded tape, or edge damage)
- Magnetic detection to detect relative dropouts
- Tissue contamination circuitry to detect debris deposited on the cleansing tissue (should also advance the tissue accordingly to lessen the change of damaging tape due to oxide build up on the tissue)
- Reporting analysis to summarise the condition of the tape according to a set of pre-defined parameters

The cleaning machine itself must be maintained and kept clean for best performance and to reduce the risk of damaging tapes and transferring contaminants such as mould to other cassettes. Constantly check and clean the tape path with swabs dampened with isopropyl alcohol between loading cassettes. Some machines have an erase function originally intended for recycling tapes; this should be disconnected to prevent accidental erasure.

If the machine has one or more burnishing blades, clean it before every tape clean, so that excess oxide built up on the blade does not scratch the surface of the tape. Be careful when cleaning burnishing blades as they are very sharp. Check the blade for damage regularly running a thin piece of plastic such as a credit card or something similar along the sharp edge of the blade (RTI: 1994). This will give an indication whether there are any problems with the edge of the blade if the card does not run silently and smoothly. If a blade is damaged it can severely damage a tape, to a point that could cut the tape completely. For this reason, some archives have a policy not to include blades in their cleaning machines.

Cleaning a tape is also an opportunity to see how a tape performs through a machine's tape path before playback in a VTR, so the practitioner can spot problems with the tape that may not be visible through normal physical inspection, and reduce the chance of damaging the fragile, and rare, video heads in the VTR.

Constantly check for excessive oxide or debris deposited on the blade or tissue to make sure the dirty tissue is constantly being moved out of contact with the tape to avoid damage. Also check if the tape is squealing in forward or reverse mode, or having trouble spooling at normal speed. (This is sometimes referred to as binding). This will give an indication whether the tape needs a second cleaning. In such a case, the tape is showing symptoms of sticky shed syndrome or hydrolysis and may require baking.

C.5.4.4 Baking tapes

Tape baking can temporarily increase the chances of a successful playback by increasing the temperature to the tape which firms up the tape binder by restoring some of the adhesive and cohesive properties of the binder.

Baking tapes should be carried out in a professional scientific oven with a constant temperature of 50 degrees C. Replaying tapes warm can greatly improve the chances of a successful playback for tapes showing signs of hydrolysis.

Additional information on hydrolysis and baking is provided in sections C.1.3.2.3 and C.1.3.4.

C.5.5 Replay equipment (playback VTRs)

Due to the longevity of the format and its widespread adoption in broadcasting, U-matic VTRs saw considerable evolution over time. Engineers prefer the newer Sony Broadcast Video U-matic (BVU) and VO series decks since they have more professional features than other models, including balanced-line XLR output for higher quality audio reproduction, RF/Tracking indicator, time code, and dub output (Sony: 1989). These machines were designed for easy integration into a professional video infrastructure. In contrast, engineers avoid the early 1970 top-loading U-matic VTRs, since their performance is inferior to the newer machines and spares are very hard to find.

As replay equipment is becoming scarce and later model broadcast decks are not always available, an overall inspection of the U-matic tape collection identified for digitisation will help to determine what type of VTR could be used. In some cases, a "lesser" VTR like an SP-compatible deck or a low-band NTSC deck will serve. If the archive's collection has many copies in different television standards, however, then a multi-standard PAL/NTSC/SECAM playback VTR would be desirable.

An archive (or its contractor) will have a better chance of successful reproduction if they are able to try playing sample or troublesome tapes on more than one U-matic VTR. Each VTR will have slightly different head wear and tape handling characteristics, and one can sometimes obtain better playback for a given tape on the "other" machine.

Technical monitoring equipment such as waveform monitors and vectorscopes are critical when replaying U-matic tapes. This equipment is needed to calibrate luma and chroma signals and can be used to view sync and burst signals, check for vertical interval information, and to monitor other technical features.

Professional-quality and calibrated CRT monitors are also useful for monitoring the output from the U-matic VTR, as these monitors have under-scan capabilities and reproduce the composite image output in its original analogue format. This is especially useful when determining the difference between a recorded artefact as compared to an artefact generated "this time" on playback. The intervention of another picture-conversion process, needed to produce an image on a digital monitor, adds to the difficulty of tracking down the source of the artefact. Such an A/D conversion to support a digital-monitor display is not, after all, a part of the critical signal path for digitisation.

C.5.6 Recording formats

There are three video recording standards for U-matic. When identifying the recording standard, there are a few indicators that will assist in identification:

- Some series of cassettes only support one recording format (see format description below)
- High-band recordings will replay as black and white in a low-band VTR
- Some VTRs have an SP/High-band indicator that will illuminate when a SP/High-band recording is played back

C.5.6.1 Low-band

Low-band is the original format for U-matic, but came to be known as low-band only after the release of high-band U-matic systems. Sony BRS series cassettes are only capable of low-band recording.

C.5.6.2 High-band

Announced in 1978, BVU (Broadcast Video U-matic), or high-band, was introduced to the market in the early 1980s. With increased capabilities for chroma subcarrier frequency options, high-band became the new ENG (Electronic News Gathering) standard, replacing 16mm film in newsgathering and production.

C.5.6.3 SP

SP (for Superior Performance) was introduced in 1986 and was developed with a chrome-based SP series tape that offered a higher frequency response than high-band. This format also supported audio recording with Dolby Noise Reduction Type C. The Sony KSP and Quantegy SPA series of videocassettes support the SP recording mode. KSP series tapes have two detection holes on the bottom of the cassette, located above and below the record tab. These holes automatically set the VTR into SP record mode if available (Sony: 1989).

C.5.7 Equipment maintenance for U-matic VTRs

Maintaining the U-Matic VTR is critical to perform best performance and playback reproduction, and to reduce the risk of damaging tapes. Cleaning the VTR is an integral part of the on-going maintenance process.

Since older tapes shed oxide and regularly clog the heads, cleaning the VTR with a standard Sony KCS-5cl cleaning tape is generally not sufficient. We recommend manual cleaning of the tape path and video heads. Cleaning cassettes are quite abrasive and excessive use of the cleaning cassette will shorten the life of the heads, so use only when necessary (Sony: 1989).

Make sure power is disconnected before taking the top panel off the machine. Clean the heads with either a chamois or lint free tissue moistened with isopropyl or other approved head-cleaning product. Clean the heads by rotating them and lightly pressing the cloth against the head drum. Clean the heads until the tissue is not wiping off any oxide. **Never move the cloth vertically up or down as this can break the heads.**

Clean the tape path including the audio heads, erase head, tape guides and rollers, and demagnetise the audio heads. Clean compressed air is also useful for removing dust and oxide from the internal workings of the VTR.

Periodically the machine should be repaired and electronically and mechanically aligned by a qualified engineer. Sony states that head life is from 500 to 1000 operating hours (Sony: 1989). However, an engineer can measure the tip penetration of the heads to determine the expected longevity of the heads. If the video picture is deficient after head cleaning, this could indicate that the heads need replacing.

Perishables such as pinch rollers and belts should be checked and replaced periodically.

Parts and spares are proving to become harder to locate, so seek out other working/non-working machines from which to harvest spare parts. A stockpile of parts, and operation and service manuals and diagrams, and the expertise to replace parts is critical to ensure the life of a VTR for the length of a digitisation project.

C.5.8 Equipment alignment for U-matic VTRs

C.5.8.1 Calibration tapes and test media

In 1993, SMPTE published a thorough *Specifications for Subjective Reference Tapes for Helical-Scan Videotape Reproducers for Checking Receiver/Monitor Setup*.[60] Unfortunately, such calibration tapes for U-Matic are rare at best. The next best thing is a tape that has a recorded signal (such as EBU 75 percent Colour Bars with +4 db 1 kHz test tone) that has been recorded on a broadcast quality machine in excellent condition and verified as a qualified test tape by a video engineer. In section D.1.3.1.4.4.4, this category of test tape is termed *house-made (or third party) VTR alignment and calibration tape*. Playing this house-made alignment and calibration tape will assist the video practitioner with identifying the source of some issues, determining whether they have been caused by a problematic U-matic tape or from a fault with the VTR.

C.5.8.2 Correction and adjustment for satisfactory replay

Calibrate the signal from the VTR using all the available controls and settings on the VTR to reduce the amount of playback errors.

Adjust the VTR's tracking, colour lock, and skew settings to obtain the most accurate reproduction possible, as described in the following subsections.

C.5.8.2.1 Tracking

This should always be adjusted to the position that gives the maximum RF reproduction for every cassette. Slowly rotate the tracking control to obtain the strongest signal on the tracking meter. If the VTR does not have a RF indicator, the tracking knob should be adjusted to produce a stable picture with the least amount of noise.

C.5.8.2.2 Colour lock

If there are obvious colour problems on playback such as incorrect chroma phase, or severe colour imperfections, selecting the different colour lock positions may provide an in-phase colour reproduction.

C.5.8.2.3 Skew

If there is horizontal distortion in the upper most part of the picture, this can be corrected by the adjustment of the skew lever at the front of the VTR. Not to be confused with the horizontal distortion at the bottom of the picture, which is a head-switching error inherent with the format.

60 "SMPTE Recommended Practice: Specifications for Subjective Reference Tapes for Helical-Scan Video Tape Reproducers for Checking Receiver/Monitor Setup," *SMPTE Journal*, Oct. 1993, vol. 102, no. 10 (DOI: 10.5594/J15910), pp. 979-981, http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7238740&isnumber=7238712, accessed 10 December 2017.

C.5.9 Sound tracks

Two longitudinal audio tracks are supported by the U-matic format, with Dolby Noise Reduction decoding available on the SP series VTRs. If a soundtrack is recorded with Dolby NR and played back on a VTR that is not equipped with a Dolby NR system, treble will be boosted.

C.5.10 Time code for U-matic videocassettes

If longitudinal time code exists on the tape, the VTR needs to be equipped with an optional TC card to reproduce the code. Optional boards exist for reproducing user-bits or LTC like the BKU-705, BKU-704, or BKU-905. VITC was also supported late in the life of U-matic.

C.5.11 Time factor for transfer of U-matic videocassettes

Due to the process of cleaning video heads often, and the need to bake and clean tapes, U-matic is a very time-consuming format to transfer. It may be only possible to play parts of the tape, and edit sections together at a later date.

Prestospace recommend U-Matic transfers take between 1–2 hours of operator time per hour of programme material for tapes in good condition, rising to 5–10 hours per hour or more for difficult media (Addis and Veres: 2007).

C.5.12 Time base correction for U-matic videocassettes

Time base correctors (TBCs) are integral to obtaining a stable picture in preparation for digitisation. They can introduce new and stable sync, increase quality, and provide the opportunity to calibrate video and audio levels through processor amplifiers.

There are many different TBCs on the market, and all treat video differently. Some TBCs have wide tolerances for handling poor quality heterodyne video, while others require a more stable input for improved performance.

Older TBCs that were originally designed to be used with U-matic can reproduce a good quality signal, and some TBCs (such as the BVT-500) have the advantage of a "dub input," which will input the luma and chroma signals separately rather than as a composite signal that adds unwanted artefacts, such as dot crawl. Other composite TBCs have optional U-matic heterodyne colour processors designed especially for the format. Machines can also be modified to extract the luma and chroma from the VTR as separate signals, i.e., before they are muxed (multiplexed, i.e., combined) into composite (Greatbear: 2013).

We recommend using a full frame, full bandwidth TBC, with professional BNC connectors, and thus ready for integration into the video archiving environment. Automatic controls such as Automatic Chroma Control (ACC) and Automatic Gain Control (AGC) are usually not advised, as they can increase original levels inappropriately.

The most obvious method of testing a TBC for the use with U-matic is to evaluate using a known problem tape. If possible, having two or more TBCs can be beneficial, as sometimes one TBC can act poorly with one tape, while the second will give a more acceptable result.

C.5.12.1 Radio frequency (RF) support

Some TBCs have an *RF* input option, which is used for logging original quality of signal reproduced from the tape through the RF output on the VTR or can be utilised when true dropout compensation is selected.

C.5.12.2 Enhancement functions of the TBC

C.5.12.2.1 Dropout compensation

Dropouts are typically a gap in a single horizontal line of picture, generally defined by engineers as a decrease in the output signal by more than 12dB for more than 5µs (microseconds). With U-matic videocassettes, dropouts can be reduced by tape cleaning, but deterioration caused by aging means that dropouts will still be present on most U-matic tapes.

Dropout compensators (DOCs) are tools that detect the gaps and fill them with a "near neighbour" video segment to produce an output video signal that is dropout-free (Busby, Trytko, and Wagner: 1986). DOCs are an integral part of broadcast replay chain and ensure that the signal continuity meets broadcast requirements. In systems like the ones being described here, dropout compensation is triggered by a loss of RF signal and consists of substituting a video signal from the nearest scan line that has the same encoding structure (Dhake: 1999).

Dropout compensation presents a dilemma to the video archivist. On the one hand, media archivists adhere to the principle that the content of a tape should be retained without change in a digital *preservation* file, i.e., as an uncorrected transfer. Corrective improvements, according to this principle, ought to be applied only to subsidiary copies, an action that is sometimes called *restoration*. On the other hand, however, the TBC and DOC are located at the last point in the playback chain where the RF signal is available to objectively indicate where a loss of signal is a genuine dropout. That is, *this* is the time and place in the digitising process where dropout compensation can be effectively accomplished.

For these reasons, the IASA-TC 06 authors recommend that dropout compensation be carried out when digitising and, if at all possible, that the process is documented as a part of preservation metadata. Some TBCs may be able to log any compensation undertaken or, if that not possible, the metadata should note that a given transfer was carried out using systems that provide dropout compensation.

C.5.12.2.2 Noise reduction

Another enhancement function is noise reduction (NR). NR in TBCs (sometimes provided by devices that also offer frame synchronisation)[61] is usually automated, which in most cases is imperfect in determining the difference between video noise and moving texture.

High quality legacy TBCs and combo-devices have *adaptive noise level reduction*, or *recursive filter* controls that are controlled manually. (One example is the Snell & Wilcox TBS24.)[62] These controls can be quite effective in attacking and reducing composite-based artefacts and noise, but it is a very time-consuming process to calibrate high and low frequency and gain adjustments.

61 Video frame synchronisation refers to the process of matching the timing of an incoming video source to the timing of an existing video system, e.g., one employed by a television studio governed by a master synch generator (an exceedingly accurate "clock"). The frame synchroniser uses the process to correct certain flaws that may arise in video playback, such as horizontal and vertical timing and the phasing of subcarrier to horizontal (SC/H) chroma signal. Video frame synchronisation supports format conversions, such as Standard to High Definition or PAL to NTSC, as well as the types of transfers used when digitising for preservation.

62 See *TBS24/T/D/TD TBS Synchroniser Operator's Manual* (Snell & Wilcox: 2005); the manufacturer describes the TBS24 as a "TBC [Time Base Corrector] Synchroniser".

Although enabling both DOC and NR functions may not be considered a purely preservation outcome, this moment in the transfer process is the last opportunity to attack analogue-based issues such as dropouts and noise in the analogue and RF domain. Proper calibration requires replay testing to achieve the best result, and this may mean repeated playback of fragile original media and significant time spent on one cassette. The first is a bad practice ("don't play old tapes too often") and the second is likely to absorb a scarce resource. Thus, special calibration functions are generally inappropriate for mass digitisation, although they may be helpful custom actions for selected historical recordings of high interest.

Most moving image restoration tools available on the market today are for cleaning up film-based artefacts, such as emulsion tramline scratches, or colour dye fade. There are only a few tools currently on the market for addressing dropouts, to support the automated restoration of digitised collections. Dropouts can be difficult to detect automatically without the analogue RF output from the VTR; as noted earlier, a good quality DOC module will mask the dropout in the analogue realm.

C.6 ½-INCH ANALOGUE CONSUMER AND SEMI-PROFESSIONAL VIDEOCASSETTES

C.6.1 Introduction

The introduction of ½-inch analogue cassette tape formats marked the beginning of a consumer revolution in home recording. The technology for domestic video recording was pioneered in the 1960s with the reel formats like those described in section C.2, *EIAJ and Sony CV ½-inch Open-Reel Videotapes*. With the videocassettes described in this section, launched in the 1970s, the ½-inch (12.5mm) tape width and slow linear running speeds brought about a dramatic reduction in running costs compared to open reel formats, as well as ease of use of through the use of cassette enclosures.

These low-cost formats opened the way for many novel semi-professional, non-broadcast uses for video recording, including home movies and family histories, the recording of theatre and dance company performances, music recordings, independent commercial releases, as well as off-air recordings of programmes for which the broadcast master may no longer exist. Home movies made with early domestic video cameras or camcorders are an invaluable source for social observation. Academics and researchers also embraced the affordable technology and applied them to documentation in the fields of linguistic, ethnographic, social science, music, dance, and medical research, and many more unexpected fields of endeavour. Although these tape formats may be less richly endowed in technical terms than those employed by broadcasters, their widespread use in research and production gives them "semi-professional" technical status.

The earliest ½-inch analogue consumer formats were proprietary. As popularity in domestic video recording grew, suppliers competed for a larger share of the market, often by making agreements with other manufacturers to secure wider support for a particular format. In the face of consumer adoption of standardised formats, manufacturers were later forced to drop their own format and eventually adopt Betamax or VHS, with VHS finally emerging as the sole ½-inch analogue format for consumer and semi-professional use.

Many of the earlier formats were produced in only one broadcasting standard, with possibly only VHS and Betamax being available in PAL, NTSC, and SECAM standards.

All ½-inch analogue consumer cassette tape formats utilise the heterodyne or 'colour-under' process pioneered by the U-matic format, thereby reducing the bandwidth required to record a composite colour television signal. The very slow linear tape speed results in compromised quality video and audio compared to professional broadcast formats. Some manufacturers applied improvements as the formats matured, particularly in the cases of Betamax and VHS.

C.6 Table 1. Chronology of ½-inch consumer and semi-professional formats

Format name	Manufacturer/s	Years in use
VCR (N1500) VCR-LP (N1700) SVR	Philips Grundig/ITT	1970–1977
Cartridge National	National/Panasonic	1971–1980
Cartrivision	Avco	1972–1973
V-Cord V-Cord II	Sanyo	1972–1976
VX	Quasar/Panasonic	1974–1978
VK	Akai	1975–early 1980s
Betamax	Sony/Sanyo/Toshiba	1975–2002
VHS	JVC/Matsushita/Mitsubishi, many others	1976–2008
Video2000/VCC/ V2000XL	Philips/Grundig/ITT	1979–1988

Most of the information in the preceding table was derived from the *Little Reference Guide for Small Video Tape Collections* (TAPE: 2008); information about Cartrivision was derived from the *Cartrivision Site* (Perry: n.d.).

C.6.2 Selection of best copy

The ½-inch formats allowed easier duplication of non-copy protected material, so it is possible that duplicates of the same content may exist within the same collection. But the lower quality offered by domestic formats compared to professional formats meant the quality of copies often suffered greatly within a very small number of successive generations. Care must be taken to select the most original (least generation or "earliest version") copy of a particular item. The carrier or protective case may be clearly indicated as *original* or *master*, but this may not always be the case.

Cassette-based formats are usually housed in a protective outer case, shell or sleeve. These cases can be an important source of descriptive and technical metadata for the carrier. It should be noted (especially for home-recordist collections) that cases for similar formats were sometimes swapped amongst carriers, so the information contained on the case may not necessarily reflect the carrier's content.

Cassettes from home recordists may include off-air recordings that will be of inferior quality compared to masters generally held in broadcast collections. However, there have been cases of long-lost programmes being discovered in a home collection that were subsequently utilised to partially or completely replace a missing broadcast master, e.g., in the case of some rare episodes of the Doctor Who television series (Roberts: 1992-93).

A collection from a production company may include viewing copies of higher quality formats, made on domestic systems for convenience or as a cost-saving measure. These may include a time code 'burn-in' display from the original broadcast tape or film. There would usually be no need to preserve these cassettes if the masters still exist. However, VHS was heavily used as a broadcast offline editing system and different versions of edits may exist on VHS which could provide an interesting record of how a production developed during the editing stage, even though a final broadcast edit master may be readily available.

Production company collections may also include standards-converted duplicate copies of cassettes. These should not be used as a source for digitisation if an original-standard recording of higher quality is available.

C.6.3 Cleaning and carrier restoration

A full visual inspection of cassettes must be carried out prior to preservation. This is normally straightforward with formats such as VHS and Betamax, but may be more difficult with less familiar formats.

Domestic cassettes are more likely to have been damaged and less well looked after compared to professional formats. The plastic parts of the cassette housing may be broken and not functioning properly. In the worst cases, they may dislodge from the cassette and damage the tape or the player when inserted in the machine. As such, any loose or rattling parts need to be repaired or removed prior to insertion in the playback machine. Any cassette record tabs present on the carrier should be removed prior to transfer to prevent accidental erasure during the preservation process.

If parts become loose, the cassette case can present a risk to the tape in replay. A specific example is the early Betamax cassette type that had a problem concerning internal plastic friction tabs. The tabs can become detached, and, in the worst case, be carried into the machine and damage both tape and heads.[63]

Some archives routinely remove the sticky labels from cassettes, as the adhesive may be so degraded that when inserted in a warm machine, the label peels and causes a jam. Labels are sometimes attached in such a way as to prevent the proper opening of the tape cover on the cassette. These labels must be removed prior to insertion into the playback machine. The label may include important metadata, so any information contained on the label needs to be carefully recorded prior to removal.

If the format allows visual inspection of the tape itself through a clear plastic window, check for any loose particles of oxide or evidence of mould, as well as the smoothness of the tape pack. Oxide degradation may show as white powder and potentially indicate the need for baking or cleaning. Professional cassette cleaning machines exist for later formats such as VHS, but need to be used with care. Rarer formats cannot easily be cleaned, so it may be necessary to simply rewind or fast-forward the tape whilst holding Pellon tape in contact with the tape surface.

It may be necessary to open and visually inspect tapes before transfer, especially if access to the tape is required, for example to reattach the leader or to check loose and rattling parts. Cassettes are usually disassembled fairly easily as there are often screws on the underside, which can be removed, then the cassette turned right side up again and to remove the top. This must be done with great care, as there are usually various moving parts inside the cassette, sometimes with springs attached, which can become dislocated. It may also be necessary to remove labels that bridge the halves, or otherwise slice through them with a blade. Care must be taken not to penetrate through the housing and accidentally cut the tape.

63 See "The trouble with tabs" section of the *MisterBetamax* website (MisterBetamax: n.d.), http://www.mrbetamax.com/CassetteTabs.htm, accessed 11 December 2017.

If tape itself needs repairing, it is very important to determine which side of the tape has the oxide layer so that splicing tape is only attached to the non-oxide layer or back of the tape. Splicing tape on the oxide side of the tape will almost certainly damage the video heads of the playback machine. Leader tapes, which depending on the format may consist of foil, or clear or reflective plastic, must be reattached as they are used by the playback machine as an indicator to stop the tape transport before running into the spool anchor and thereby damaging both tape and machine.

Binder degradation can be a problem with early videotape collections. Tapes were manufactured with impregnated lubrication in the oxide layer, which tends to evaporate or disappear with time and repeated use. This causes playback problems, due to increased friction and therefore tension around the tape guides and head drum. Tape and head drum wear will be increased, causing long-term harm to the playback machine and tape. Scrape flutter, caused by tape 'stiction', is also likely, causing modulation of the audio track and a wavy horizontal displacement of the image as a result of time base errors. An audible symptom of this effect is an audible squeal from the machine during playback of the tape. Playback cannot take place in these circumstances. These tapes may respond to heat treatment (baking) or cleaning techniques (see sections C.1.3.2.3 and C.1.3.4).

Cassette based formats are usually housed in a protective outer case, shell or sleeve. These cases can be an important source of descriptive and technical metadata for the carrier. The protective case should also be inspected for damage and cleanliness. Broken or dirty cases should be replaced, but only after metadata contained on the case is carefully recorded. However, it should be noted (especially for home recordist collections) that cases for similar formats were sometimes swapped amongst carriers, so the information contained on the case may not necessarily reflect the carrier's content.

C.6.4 Typology of ½-inch formats and replay equipment (playback VTRs)

Finding the right equipment to play consumer formats is difficult. Although equipment may have been made in large quantities for certain formats (compared to broadcast machines, which was a specialist market), earlier format machines will have been out of use for a long time, and most will have been scrapped. Some formats, like Cartrivision, V-Cord, Akai VK, and VX, were only made in small quantities for a short period of time, so working machines are very rare. Where a format flourished for a longer period, particularly VHS and Betamax, but also VCR and V2000, it is generally better to try to select a later model of machine, if the choice exists, as many refinements were built in as the technology improved. Except in certain circumstances (outlined below), machines were usually backwardly compatible with earlier recordings.

In some cases, a variety of playback machines of the same format may be required. Although some formats retained cassette dimensions during their evolution the recording format could vary, leading to potential compatibility issues. This can range from differing speeds used during recording, e.g., VHS Standard play vs VHS Long play, to completely different head configurations, e.g., Philips VCR vs VCR-LP, associated with the Philips N1700 recorder (Total Rewind: n.d., section devoted to N1700[64]).

64 See the "Philips N1700" section of the *TotalRewind* website (TotalRewind: n.d.), http://www.totalrewind.org/philips/P_1700.htm, accessed 11 December 2017.

C.6.4.1 Philips VCR cassette format

C.6.4.1.1 History

The VCR format was designed by Philips around 1970 and was the first successful home video recording system. The three main versions of VCR[65] are the standard play Philips VCR (N1500), the long play Philips VCR LP (N1700) and Grundig/ITT SVR (TAPE: 2008, section devoted to VCR recorders).[66]

C.6.4.1.2 Recording formats

All VCR versions use the same cassette design with co-axially arranged reels, i.e., the take-up reel is placed on top of the supply reel (Jackson and Townsend: 1991, p. 56.1). The tape loop is drawn out around the head drum from a flap at the front of the tape, and the pinch roller and audio/control track head access the tape through a flap in the right-hand side.

In common with most ½-inch analogue consumer formats, the heterodyne colour process was used, with a colour-under frequency, in this case, of 562.5 kHz, giving a chroma resolution of approximately 28 horizontal lines. A luma dropout compensator was provided and, interestingly for times well before S-VHS, a DIN plug with separate luma and chroma outputs was provided on some machines (Ripley: 1975).

The original N1500 series of machines ran at 11.26 inches per second, with available cassette sizes of 30, 45 and 60 minutes. The 60-minute cassettes used thinner tape and are subsequently more susceptible to jams and breakages during playback than the cassettes with shorter running times. The format is subject to poor compatibility, as tapes may only successfully replay on the actual machine used for the recording.

The N1700 series machines, developed around 1978 and known as VCR-LP, used slant-azimuth that enabled a lower linear playing speed and the elimination of the guard-band between video tracks (Jackson and Townsend: 1991, p. 56.1). These recordings are incompatible with the earlier N1500 replay machines. The same tape stock could be used for both, making it difficult to determine which machine is needed as there is unlikely to be anything indicating which type of recording is on a tape. We are not aware of any models that could play both formats.

SVR (Super Video Recording) was the final development of VCR by Philip's sister company Grundig, just before the format was abandoned in favour of V2000 in the late 1970s. Several models were produced with an even slower tape speed and longer running time, using Agfa or BASF chrome dioxide tape with a special identifier hole in the base. Again, these recordings are incompatible with earlier machines, and sometimes even with the machine that made the original recording.

C.6.4.1.3 Sound tracks

Either one or two audio tracks are available, depending on the machine. The Philips/Grundig VCR format, in its second manifestation, added a second audio track in a different position on the tape. Unlike other formats, which simply split the mono track into two stereo tracks, the second audio track, if used, is on the top edge of the tape, above the control track, while the main audio track is on the bottom edge.

65 Wikipedia, *Video cassette recording*, https://en.wikipedia.org/wiki/Video_Cassette_Recording, accessed 11 December 2017.

66 See the "VCR-1500 / 1700" section of the *Reference Guide for Small Video Tape Collections* (TAPE: 2008), http://www.little-archives.net/guide/content/6_vtr.htm, accessed 11 December 2017.

C.6.4.2 National/Panasonic Cartridge Format

C.6.4.2.1 Recording formats

The National/Panasonic Cartridge format consists of a supply reel of EIAJ-1 format tape in a square coaxial cartridge. The recorder/player automatically laces the stiff plastic leader tape onto a take-up reel within the machine. Apparently prone to tape damage, the format had a maximum recording time of 60 minutes.

C.6.4.2.2 Sound tracks

The National Cartridge format had a single mono audio track.

C.6.4.3 Avco Cartrivision format

C.6.4.3.1 History

The Cartrivision developed by Avco is notable as the first cassette format available to the public in the USA. The format was very short-lived, and only one model of player was produced, usually built-in as part of the television set.

C.6.4.3.2 Recording formats

The square cassette contained two coaxially mounted reels. Although it recorded in colour, it used a form of 'skip-field' video compression by recording every third video field, and then repeating each field three times on playback to achieve normal duration length (Abramson: 2003, p. 134; Mee, Daniel, and Clark: 1999, pp. 187-88).

C.6.4.3.3 Sound tracks

The Cartrivision home VTR recorded with mono audio, but was able to reproduce stereo audio from pre-recorded commercial cassettes.

C.6.4.4 Sanyo-Toshiba V-Cord I and II formats

C.6.4.4.1 History

Sanyo and Toshiba produced this system between 1974 and 1976. It consisted of a Vidicon camera connected to a separate recorder via multicore cable. The system was adopted for field recording use due to its relatively low cost and lightweight and some significant ethnographic collections were recorded using this technology.

C.6.4.4.2 Recording formats

The original V-Cord format (V-Cord I) from 1974 recorded composite black and white video only. The machine used a conventional two- or four-head, 180˚ wrap, near-perpendicular scan mechanism. V-Cord II developed in 1976 provided the capability to record composite colour, as well as black and white. V-Cord II four-head machines were capable of slow motion and still picture, but produced recordings which were incompatible with the two-head system. Linear tape speed is 11.47 cm/sec for standard playback, 2.87 cm/sec for slow motion playback. Resolution of the system is approximately 200 lines.

The tapes have a similar shape to 8-track audio cartridges (Abramson: 2003, p. 170). The tape opening is on the left-hand side of the cartridge, which loads into the mechanism on the right of the tape transport rather than in front of it. V-Cord I cartridges are usually housed in a green or white case and have a running time of 60 minutes. The later V-Cord II cartridges are usually housed in a brown or black case and were able to record with two speeds, offering running times of 60 and 120 minutes.

Examples of playback machines include:

- Sanyo: VTC 7300 (colour), VTC 8000, VTC 8200
- Toshiba: KV-4100, KV 4200

Blank tape duration designations are as follows:

- V-Cord I – VT 5C: 6 minutes, VT 10C: 12 minutes, VT 20C: 24 minutes
- V-Cord II – V 60: 60 minutes, V 120: 120 minutes

Before attempting to play this format, it is advisable to disassemble the cassette, *carefully* noting where component parts are located as they are difficult to re-assemble. Clean both sides of the tape, as some tapes can be sticky, and others shed oxide and clog the heads. Spool the tape and re-attach each end of the tape to the hubs to prevent the original glue detaching during playback. If the original rubber brakes inside the cartridge have perished, they can be replaced with short pieces of 2mm silicon tubing.

C.6.4.4.3 Sound tracks

The V-Cord format has a single mono audio track.

C.6.4.5 Quasar VX Cartridge Format

C.6.4.5.1 History

VX was manufactured in the USA by Quasar and also sold by Panasonic/Matsushita (Abramson: 2003, p. 170). It was a very short-lived format.

C.6.4.5.2 Recording formats

The VX format used coaxially mounted reels contained in a rectangular cartridge to allow for a permanent threading loop inside the case. The cartridge is similar in size to the U-matic cassette. The cartridge drops down into the machine over the head drum, audio heads and capstan/pinch roller, so virtually no lacing is required. The tape wrap is almost 360 degrees with a single video head. Recording up to 2 hours on the longest available tape and video quality was reasonably good for its time.

C.6.4.5.3 Sound tracks

The VX format has a single mono audio track.

C.6.4.6 Akai VK Videocassette Format

C.6.4.6.1 History

The VK format was developed by Akai in the late 1970s for use in its range of portable video recorders and cameras (camcorders).[67]

C.6.4.6.2 Recording formats

The format used a standard-style cassette similar in size and shape to Betamax, with a maximum recording duration of 30 minutes. The tapes can be distinguished by the finger hole at the rear of the cassette and the fact that the supply reel is wound in the opposite direction to usual, both features similar to the U-matic format. Since portable camcorder kits were sold by Akai, collections may include unique camera recordings.

C.6.4.6.3 Sound tracks

The VK format had a single mono audio track.

67 Wikipedia, *Akai VK*, https://en.wikipedia.org/wiki/Akai_VK, accessed 11 December 2017. See also the "Akai VT-300" section of the *TotalRewind* website (TotalRewind: n.d.), http://www.totalrewind.org/portable/Q_VT300_main.htm, accessed 11 December 2017.

C.6.4.7 **Sony Betamax videocassette format**

C.6.4.7.1 History

Sony developed the Betamax domestic format in the early 1970s based on their earlier work with the U-matic system (Abramson: 2003, p. 158). Betamax was brought to market in 1975 in Japan, and a year or two later in the US and Europe.

C.6.4.7.2 Recording formats

Betamax uses a standard left to right cassette configuration, with a window over the left hand spool. The Betamax cassette housing is common to all Sony half-inch formats, including later professional broadcast formats, although the tape formulations are very different. The tapes are named according to their length in feet, so, for instance, an L-750 is 750 feet long (229 m).

The Betamax specification was licensed to several other manufacturers, who produced their own machines. There are nominally three forms of Betamax, known by Roman numerals: *Beta I*, *Beta II*, and *Beta III* (Camras: 1988, p. 507). The numerals denote tape speed and therefore recording times. The highest speed of the original Beta I quickly fell out of use due to relatively short recording times. Beta II doubles the recording time of Beta I and is the most common form used. Beta III runs at two-thirds Beta II speed, with playing times 1.5 times longer again (triple the time of Beta I).

All three forms may be used for NTSC recordings, with Beta II being the most common. Beta II is the only form available for PAL recording.

C.6 Table 2: Common tape lengths for Betamax

Tape label	**Tape length**		**Recording time**			
	ft	**m**	**B I**	**B II**	**B III**	**PAL/ SECAM**
L-125	125	38	15 min	30 min	45 min	32 min
L-165	166 2/3	51	20 min	40 min	60 min (1 h)	43 min
L-250	250	76	30 min	60 min (1 h)	90 min (1:30 h)	65 min (1:05 h)
L-370	375	114	45 min	90 min (1:30 h)	135 (2:15 h)	96 min (1:36 h)
L-500	500	152	60 min (1 h)	120 min (2 h)	180 min (3 h)	130 min (2:10 h)
L-750	750	229	90 min (1:30 h)	180 min (3 h)	270 min (4:30 h)	195 min (3:15 h)
L-830	833 1/3	254	100 min (1:40 h)	200 min (3:20 h)	300 min (5 h)	216 min (3:36 h)

The information in the preceding table was derived from the Wikipedia, *Betamax* article, heading "Tape Lengths," https://en.wikipedia.org/wiki/Betamax#Tape_lengths, accessed 11 December 2017.

The Betamax specification was expanded over its life cycle with a number of enhancements. The SuperBeta feature provided on certain machines after 1985 increased the luma carrier frequency resulting in higher horizontal resolution. SuperBeta recordings may still be playable on machines without the SuperBeta facility.

Beta I was reintroduced late in the life of the format in NTSC, in order to provide a high quality *HiBand* version with an even higher luma carrier frequency (Mee, Daniel, and Clark: 1999, p. 191), along with a slightly lower quality version known as *BIs* (SuperBeta I). Towards the end of Betamax in the late 1980s, Extended Definition Betamax, based on new, high coercivity ED-Metal tapes[68] was introduced.

The abovementioned video improvements all result in some increase in luma resolution (and chroma, in the case of ED) as well as an improvement in video signal-to-noise ratio, but potentially at the expense of some interchangeability (Mee, Daniel, and Clark: 1999, p. 191).

Apart from a label indicating the use of ED-Metal formulation in the case of Extended Definition Betamax cassettes, it may not be possible to tell before playback what form of signal is on the tape based on visual inspection of the cassette housing. Therefore, several different types of replay machine may be required in order to correctly transfer a single Betamax recording.

The regular version of each Beta format will play on most SuperBeta and Beta HiFi models, except very early Beta I machines. Conversely, SuperBeta tapes may play on regular Beta machines, but they are likely to exhibit picture tearing (white and black flecks on high contrast edges), due to over-modulation. ED Beta was mainly an NTSC format, although some PAL machines, and therefore tapes, are to be found in the Middle East. ED Beta requires the use of "metal" tapes, so brands such as *ProX* may indicate the need for an ED playback machine. If there is doubt on which Betamax format is applicable for a particular carrier, consider using the latest model of playback machine available, ensuring the correct television standard is applied.[69]

Unlike most other domestic formats mentioned, Sony developed at least one "industrial" style semi-professional player for NTSC Betamax, the GCS-50. The GCS-50 has a number of enhanced features ideal for routine NTSC transfer work, such as multi-format playback, real time counter display and a head meter for the number of hours of use.

C.6.4.7.3 Sound tracks

The Betamax format originally recorded audio as a linear mono track. The format then introduced two separate audio tracks in 1982 by splitting the mono track. Proprietary noise reduction was introduced, known as *BNR* (Beta noise reduction), in order to provide some improvement in signal to noise ratio, via an on/off switch on the front panel. Care needs to be taken that the noise reduction is correctly decoded during playback.

HiFi audio was introduced the next year, using the existing video heads in NTSC, but adding an extra pair of HiFi audio heads to the head drum for PAL. The quality is claimed as 80dB dynamic range, but frequently suffers from mistracking and crosstalk from the video tracks, causing a buzz on the audio, which may also be a product of the head switching. Playback machines without HiFi audio capability will only play the linear audio tracks.

As the format supports both HiFi and linear audio, consideration should be given to whether both audio formats should be captured.

68 See the "Sony Betamax Compatibility" section of the *MisterBetamax* website (MisterBetamax: n.d.), http://www.mrbetamax.com/BetaCompatibilityVCRs.htm, accessed 11 December 2017.
69 *Ibid.* This article includes a table illustrating Sony machine compatibility for NTSC playback.

C.6.4.8 VHS (Video Home System) videocassette format

C.6.4.8.1 History

Launched a year after Betamax, the VHS (Video Home System) was the open standard backed by JVC against the licensed standard produced by Sony (Abramson: 2003, p. 169). Although early VHS machines were of slightly lower quality then Betamax, the format's longer recording time and open standard encouraged many different manufacturers to take up production of the format. Machines became available on domestic markets in Japan, Europe, and America in 1977.

The VHS format eventually outlived Betamax, partly due to the number of manufacturers and lower costs, as well as the relative cheapness and availability of spare parts. The higher availability of commercial titles in VHS format played a significant, and non-technical, reason for the overwhelming popularity of the format.

No widespread developments were made to analogue VHS after the late 1990s. In 1994, JVC developed the W-VHS format to accompany the Japanese Hi-Vision analogue high-definition television system, enabling high-definition analogue recording on a VHS-sized cassette[70]. In 2002, JVC further adapted the VHS cassette to develop the D-VHS[71] and D-Theater[72] systems, amongst the first physical delivery formats for digital high-definition video for consumers. However, the increased adoption of DVD and later hard drive recorders led to the demise of the VHS format in the late 2000s, marking the end of the era of tape-based domestic recording.

C.6.4.8.2 Recording formats

The larger dimensions of the VHS cassette can accommodate longer tape compared to Betamax (1400ft as against 830ft in the case of Betamax), allowing longer recording times despite the slightly higher linear tape speed than that of Betamax. With a smaller head drum compared to Betamax (although similar in size to the V2000 system), the theoretical video quality is lower than that possible with Betamax. Other features of the two formats are broadly similar, although the smaller head drum in VHS-C camcorders (Beeching: 2001, p. 179) meant that, in conjunction with compact VHS-C cassettes, smaller, portable camcorders became more feasible and popular.

The main differences between recordings, necessitating the correct machine for playback, are the international TV standards (NTSC, PAL, SECAM). Multi-standard machines do exist, but care must be taken to ensure that machines with a built-in standards-converter of some form are avoided, as transfer and preservation needs to be carried out in the native TV standard of the recording.

VHS cassettes are labelled according to their running time in minutes, rather than length in feet. PAL and SECAM machines run slightly slower than NTSC machines. NTSC times are designated with a leading *T* (as in *T-60* for one hour) in NTSC and European formats (such as PAL and SECAM) are designated a leading *E* (as in *E-60* for one hour).

70 Wikipedia, *W-VHS,* https://en.wikipedia.org/wiki/W-VHS, accessed 1 September 2016.
71 Wikipedia, *D-VHS*, https://en.wikipedia.org/wiki/D-VHS, accessed 1 Sep 2016.
72 *Ibid.*

C.6 Table 3. Common tape lengths for VHS

Tape label (nominal length in minutes)	Tape length		Rec. time (NTSC)			Rec. time (PAL)	
	m	ft	SP	LP	EP/SLP	SP	LP
NTSC market							
T-20	44	145	22 min	44 min	66 min (1h 06)	31.5 min	63 min
T-30 (typical VHS-C)	63	207	31.5 min	63 min (1h 03)	95 min (1h 35)	45 min	90 min (1h 30)
T-45	94	310	47 min	94 min (1h 34)	142 min (2h 22)	67 min (1h 07)	135 min (2h 15)
T-60	126	412	63 min (1h 03)	126 min (2h 06)	188 min (3h 08)	89 min (1h 29)	179 min (2h 59)
T-90	186	610	93 min (1h 33)	186 min (3h 06)	279 min (4h 39)	132 min (2h 12)	265 min (4h 25)
T-120 / DF240	247	811	124 min (2h 04)	247 min (4h 07)	371 min (6h 11)	176 min (2h 56)	352 min (5h 52)
T-150 / DF300	316.5	1040	158 min (2h 38)	316 min (5h 16)	475 min (7h 55)	226 min (3h 46)	452 min (7h 32)
T-160	328	1075	164 min (2h 44)	327 min (5h 27)	491 min (8h 11)	233 min (3h 53)	467 min (7h 47)
T-180 / DF-360	369	1210	184 min (3h 04)	369 min (6h 09)	553 min (9h 13)	263 min (4h 23)	526 min (8h 46)
T-200	410	1345	205 min (3h 25)	410 min (6h 50)	615 min (10h 15)	292 min (4h 52)	584 min (9h 44)
T-210 / DF420	433	1420	216 min (3h 36)	433 min (7h 13)	649 min (10h 49)	308 min (5h 08)	617 min (10h 17)
T-240 / DF480	500	1640	250 min (4h 10)	500 min (8h 20)	749 min (12h 29)	356 min (5h 56)	712 min (11h 52)
PAL market							
E-30 (typical VHS-C)	45	148	22.5 min	45 min	68 min (1h 08)	32 min	64 min (1h 04)
E-60	88	290	44 min	88 min (1h 28)	133 min (2h 13)	63 min (1h 03)	126 min (2h 06)
E-90	131	429	65 min (1h 05)	131 min (2h 11)	196 min (3h 16)	93 min (1h 33)	186 min (3h 06)
E-120	174	570	87 min (1h 27)	174 min (2h 54)	260 min (4h 20)	124 min (2h 04)	248 min (4h 08)
E-150	216	609	108 min (1h 49)	227 min (3h 37)	324 min (5h 24)	154 min (2h 34)	308 min (5h 08)
E-180	259	849	129 min (2h 09)	259 min (4h 18)	388 min (6h 28)	184 min (3h 04)	369 min (6h 09)
E-195	279	915	139 min (2h 19)	279 min (4h 39)	418 min (6h 58)	199 min (3h 19)	397 min (6h 37)
E-200	289	935	144 min (2h 24)	284 min (4h 44)	428 min (7h 08)	204 min (3h 24)	405 min (6h 45)
E-210	304	998	152 min (2h 32)	304 min (5h 04)	456 min (7h 36)	217 min (3h 37)	433 min (7h 13)
E-240	348	1142	174 min (2h 54)	348 min (5h 48)	522 min (8h 42)	248 min (4h 08)	496 min (8h 16)
E-270	392	1295	196 min (3h 16)	392 min (6h 32)	589 min (9h 49)	279 min (4h 39)	559 min (9h 19)
E-300	435	1427	217 min (3h 37)	435 min (7h 15)	652 min (10h 52)	310 min (5h 10)	620 min (10h 20)

The information in the preceding table was derived from the Wikipedia *VHS* article, heading "Tape Lengths," https://en.wikipedia.org/wiki/VHS#Tape_lengths, accessed 17 August 2016.

Two versions of slow speed recording were introduced: *Long Play* (*LP*) for PAL and NTSC (Beeching: 2001, p. 150), and *Extended Play* (*EP/ELP*) for NTSC only (Camras: 1988, p. 507). Machines with the multiple speed option introduced the abbreviation *SP* for *Standard Play* (i.e., normal speed). A machine with multiple speed capability is necessary to playback such recordings.

In the mid-1980s, JVC marketed the HQ system. This attempted to increase the quality of VHS recording and playback using a combination of luma and chroma noise reduction and detail enhancement using artificial sharpening (Beeching: 2001, p. 45). Most of these modifications will introduce artefacts which would not be desirable in an archival transfer, and the use of HQ decks should be avoided.

A major evolution of the format is the Super VHS (S-VHS) system (Beeching: 2001, p. 30). Introduced in 1987, the higher coercivity tape formulations allowed a much higher luma carrier frequency to be used, which improves luma signal to noise ratio and frequency response and considerably better luminance resolution. S-VHS playback machines also introduced the S-Video connector, which provided higher video quality due to separate luma and chroma signal outputs, as opposed to the older composite connector.

S-VHS tapes played back in a standard VHS machine will exhibit white speckles and picture tearing. The colour-under frequency used for the chroma was unchanged in S-VHS, so there was no improvement in the quality of the colour part of the signal, leading some manufacturers to develop Chroma Noise Reduction (CNR) replay circuits. An S-VHS cassette has a dedicated S-VHS detection hole on the underside, which can assist as a visual check to identify S-VHS carriers (Beeching: 2001, p. 56).

Older S-VHS machines will switch into normal VHS recording mode when detecting an oxide rather than metal tape. However, JVC later produced the SVHS-ET system (Beeching: 2001, p. 56), which allowed certain machines to make S-VHS recordings on standard tapes, further complicating playback for archivists.

JVC and Panasonic, and later Sony, developed semi-professional machines for VHS. These utilise more sophisticated playback electronics, giving improved signal processing, improved transport, more professional connectors (such as BNC and S-Video) and balanced audio. As with other tape formats, use of the later manufactured machines will produce the best playback results for archival transfers. Not only is the picture quality improved and more features supported by one machine (such as HiFi audio), but more importantly, tape handling is generally more sophisticated and therefore gentler on the carrier.

Later semi-professional-standard machines are preferable for dealing with main format variants such as multiple international standards, HiFi audio and S-VHS. Alternative speeds such as Long Play or Extra Long Play can be more easily found on domestic machines, although there are some semi-professional machines that have this feature.

Semi-professional machines may also include a time base corrector (TBC). There is much discussion as to the benefits and drawbacks of using a TBC for archival transfer, as some features, such as noise reduction, may not be desirable. However, a built-in TBC is usually closely integrated with the playback processing of the machine and can greatly improve playback stability and quality, as well as provide level controls which may be needed to avoid clipping in the digitising system. Unfortunately, in the later machines, these are digital systems, but no digital output is provided, so using a TBC inserts an extra pass of A-D and D-A into the signal chain, which is generally something to be avoided.

The VHS-C format was designed for portable home-movie equipment and, as such, the 60-minute cassette of ½-inch tape is much smaller than the standard VHS cassette to fit the small housing of a camcorder (Beeching: 2001, p. 178). Later camcorders also had a smaller diameter head drum (Jackson and Townsend: 1991, p. 56.8.1), but as the recording on the tape was required to be in a standard VHS format, the wrap around the head drum was 270 degrees instead of 180 degrees and 4 video heads were used. In order to play the tape in a standard machine, a cassette adapter is used to hold the VHS-C tape and present it as a normal tape to the playback machine. Loading the tape into the adapter requires some pre-lacing to present the tape correctly, and this can be manual or battery powered, the battery being housed in space not taken up by the VHS-C tape in the adapter. It is important to note that the first few seconds of a VHS-C recording will not be accessible when using an adapter, due to the additional length of tape required for threading in a standard VHS machine (Beeching: 2001, p. 179).

C.6.4.8.3 Sound tracks

VHS audio was initially recorded as a single linear mono track at the top of the tape. Later the mono track was split into two linear channels for stereo audio. Dolby B noise reduction was applied to the linear tracks[73] to assist in hiss reduction, and care needs to be taken that the noise reduction is correctly decoded during playback. The right channel linear audio is also more susceptible to dropouts, due to its proximity to the top edge of the tape (Capelo and Brenner: 1998, pp. 150-51).

VHS HiFi audio was developed in 1984 utilising similar techniques to Betamax HiFi audio (Abramson: 2003, p.200; Beeching: 2001, p. 154). Both NTSC and PAL HiFi machines use an extra head pair for AFM (Audio Frequency Modulation) audio (Jackson and Townsend: 1991, p. 56.9). As with Betamax, most HiFi machines will record the same audio on the linear and the HiFi tracks, so either can be selected on playback, depending on whether the playback machine is equipped for HiFi. Consumer machines will do this automatically, and may switch between them randomly if there are problems with the HiFi playback. Semi-professional standard machines may enable manual switching or, preferably, feed both linear and HiFi tracks on four separate outputs. Ideally these should then all be digitised for archival purposes. This is especially important when a recording has been made on semi-professional machines that allowed the recording of four independent channels on the linear and HiFi tracks. The same audio systems are available whether VHS or S-VHS formats have been used.

Some high-end consumer machines allowed re-recording of the linear audio track independently of the HiFi audio tracks via an "audio dub" feature. This was especially used in the context of home movies and field recordings to provide narration or an alternative soundtrack, and the existence of these should be considered prior to capture of the signal.

73 Wikipedia, *VHS* article, heading "Audio recording," https://en.wikipedia.org/wiki/VHS - Audio_recording, accessed 17 August 2016.

Sidebar: Format Wars (VHS vs. Betamax and others) and PCM audio recording

Through the 1970s and 1980s manufacturers participated in aggressive competition in marketing, design, and manufacturing for the lucrative consumer market. VHS and Betamax dominated the competition, with VHS emerging the clear winner. The event has become an area for study and much has been published on the reasons for the outcome. During the format-war period, any manufacturer wishing to develop a product that depended on videotape was well advised to develop it for both of these major formats.

Meanwhile, during this time, Sony developed the PCM converter unit to record digital audio (Mee, Daniel, and Clark: 1999, p. 120). Developed from a similar unit designed for the record industry that utilised U-matic as the carrier, several different converter units were produced in PAL or NTSC formats to suit the local television standard, including the Sony PCM-F1 portable converter which acted as a companion unit to portable Betamax recorders for field audio recording. The PCM converter encodes two audio channels into Pulse Code Modulation which is converted into a relatively low bandwidth video signal which can be recorded on the video input. Though Sony was the main supporter of Betamax in the videotape format wars, the SONY PCM convertor was agnostic with regards to the tape used and was used on both Betamax and VHS machines. The 'PCM' switch available on some playback machines is used to switch off some playback processing, including dropout compensation, which can interfere with the operation of the PCM unit.

S-VHS cassettes were also used for multi-track digital audio recording purposes in the Alesis Digital Audio Tape (ADAT) format, which can only be played back in an ADAT machine.[1]

1 Wikipedia, *ADAT*, https://en.wikipedia.org/wiki/ADAT, accessed 17 August 2016.

C.6.4.9 Philips-Grundig Video Compact Cassette, Video 2000/V2000XL/VCC

C.6.4.9.1 History

Video 2000 or Video Compact Cassette (VCC) was the next-generation solution produced by the same European Philips/Grundig consortium that had developed domestic video recording with the earlier VCR format (Abramson: 2003, p 186). Although very advanced for its time, it was more expensive and arrived too late to compete with the market penetration already achieved by Betamax and VHS.

C.6.4.9.2 Recording formats

Video 2000 achieved comparatively long recording times from the start by using a two-sided, four hours per side tape design (Abramson: 2003, p. 186). Video 2000 was a very similar size and shape to VHS, but as the recording took up only half the width of the tape, both sides of the tape could be used by turning the tape over in the machine, as with audio compact cassettes (Jackson and Townsend: 1991, p. 56.7). Since the format was produced in Europe, the authors assume that all machines are PAL or SECAM only.

Machines were equipped with Dynamic Track Following (DTF) (Abramson: 2003, p. 186), probably due to the difficulties of accurately tracking the shallow wrap angle caused by the effective ¼-inch tape width. This technology in a domestic machine was advanced for its time, and had previously only been used on broadcast machines, such as the Ampex one-inch C-format (AST) and Sony Betacam (DT). DTF enabled the head to precisely follow the centre of each video track by mounting the head on a piezoelectric crystal, which could bend up or down to follow the line of maximum RF

(Jackson and Townsend: 1991, p. 56.7). Enhanced playback modes such as slow-motion playback and noiseless search were thus also enabled. Despite the use of DTF, there are still interchange compatibility issues between tapes and machines. The format has no control track, instead using a series of pilot tones on the video tracks, which may also contribute to playback issues.

A relatively large number of playback models manufactured by Philips and Grundig exist, along with others from manufacturers such as ITT and Bang and Olufsen.[74] The best machines to use for playback would be the later models produced. The Grundig Video2x4 1600 model should be avoided, as it is the only machine without DTF.

Although Hi-fi audio, Hi-band, and digital versions of Video 2000 were designed, they were never implemented. Long-play recording was developed which used half tape speed to give 16 hours running time per tape, and could be optionally implemented in the final few machines to be manufactured, such as the Philips VR2840 and Grundig Video 2x4/2x8 2080 and 2280.

C.6.4.9.3 Sound tracks

In the first production versions of Video 2000, there was, between Philips and Grundig machines, a 2.5mm discrepancy in the positioning of the audio head stack on the tape path. This means that early recordings will play with audio out of synchronisation on machines from the alternative manufacturer. Later on, both manufacturers compromised in the positioning of the head, so early recordings will still be non-synchronised, but by a smaller amount, even when played in the correct manufacturers' machine. This issue must be carefully monitored during transfer, and subsequent correction in the digital domain should be considered.

The final machines manufactured were also amongst the few to have stereo audio, produced by splitting the mono track in half, and are necessary for correct transfer of a stereo recording. Dynamic Noise Suppression noise reduction was used for the two audio tracks and must be applied on playback.

74 Wikipedia, *Video 2000* article, heading "Machines," https://en.wikipedia.org/wiki/Video_2000#Machines, accessed 17 August 2016. This offering includes a comprehensive list of model numbers.

C.6.5 Feature comparison for VHS, Betamax, and V2000 formats

C.6 Table 4. Feature comparison, selected ½-inch consumer and semi-professional formats.

System Data	VHS	Betamax	V2000
Drum diameter	62.5 mm	74.487 mm	65.00 mm
Speed of head drum	1500 rpm (PAL), 1800 rpm (NTSC)	1500 rpm (PAL), 1800 rpm (NTSC)	1500 rpm
Video Head to Tape speed	4.88 m/s (PAL), 5.81 m/s (NTSC)	5.832 m/s (PAL), 7.01 m/s (NTSC)	5.08 m/s
Tape speed (standard play)	2.339 cm/s (PAL), 3.335 cm/s (NTSC)	Beta II - 1.873 cm/s (PAL) 2.03 cm/s (NTSC)	2.44 cm/s (PAL)
Video head gap	0.3 microns	0.4 microns	0.4 microns
Video head azimuth	±6 degrees	±7 degrees	±15 degrees
Mono audio track width	1 mm	1.05 mm	0.65 mm
Audio frequency response		50Hz - 10kHz	50Hz - 10kHz
Control track width	0.75 mm	0.6 mm	none
Maximum recording time	300 mins (PAL, E300)	215 mins (PAL, L-830)	240 mins per side (PAL,VCC-480)
S/N Ratio - B/W	~45dB	>43dB	> 44dB (CCIR 421-1)
Horizontal resolution	240 lines	260 lines	3 MHz < -20db
Angle of video tracks	5 degrees 56 minutes stationary 5 degrees 57 minutes moving	5 degrees 00 minutes stationary 5 degrees 58 minutes moving	2 degrees 6473 variable
End sensor leader	Transparent optical	Inductive	Reflective optical

Much of the information in the preceding table was derived from *VCR Troubleshooting & Repair* (Capelo and Brenner: 1998) and the *Video Cassette Recorder* section of the *Introductory Consumer Electronics Technology Series* (Penn CIS: n.d.), http://repairfaq.cis.upenn.edu/sam/icets/vcr.htm, accessed 12 April 2016.

C.6.6 Maintenance and testing of ½-inch VTRs used for playback

Maintenance of the playback machine is critical to obtaining the best performance and playback reproduction, and to reducing the risk of damaging tapes during transfer. Regularly cleaning the playback machine is an integral part of the on-going maintenance process.

As older tapes shed oxide and regularly clog the heads, manual cleaning of the tape path and video heads is required. Although dedicated cleaning cassettes were manufactured for a number of the abovementioned formats, cleaning cassettes are quite abrasive and excessive use of the cleaning cassette will shorten the life of the heads, and should be avoided.

It is more beneficial to manually clean the heads, but it is a delicate procedure, and should be undertaken with care.

Make sure power is disconnected before taking the top panel off of the machine.

Carefully remove the top panel of the machine to expose the tape transport and playback heads. Some of the portable playback machine models (such as the Akai VT-300 for the VK format) have a removable cover at the rear of the machine providing easier access to the head drum for cleaning.[75] Clean the heads with either a chamois or lint-free tissue moistened with isopropyl or other approved head-cleaning product. Clean the heads by rotating them and lightly pressing the cloth against the head drum. Clean the heads until the tissue is not wiping off any oxide. Never move the cloth vertically up or down as this can break the heads.

Clean the tape path including the audio heads, erase head, tape guides, and rollers, and demagnetise the audio heads. Clean compressed air is also useful for removing dust and oxide from the internal workings of the playback machine.

The machine should be periodically checked and electronically and mechanically aligned by a qualified engineer. Electronic copies of service manuals for some playback machines are available for download or purchase online.

Dedicated factory alignment cassettes were manufactured for a small number of the abovementioned formats. In section D.1.3.1.4.4.3, this category of test tape is termed *manufacturer VTR alignment and calibration tape*. Some of these cassettes included clear housings to allow the technician to view the tape transport during alignment. For example, Sony produced a series of useful Betamax tapes (such as the KR5-2H) which contained a series of test signals, as well as a torque alignment tape which contained tension gauges in order to set up the tape handling mechanics.[76] They were often expensive items and had a finite useful life. They are now extremely hard to find and should be looked after carefully if held. They are also likely to have been well used, so care is necessary in their operation.

Perishables such as pinch rollers and belts should be checked and replaced periodically. If a machine is used only occasionally it must be checked with a sacrificial tape before a collection item is introduced in case any deterioration causes damage to the tape.

If the video picture is still deficient after cleaning the heads, this could indicate the heads need replacing. "New Old Stock" parts and spares are difficult to locate, especially for the earlier proprietary formats, so it is important to seek out and acquire other working or non-working machines from which to harvest spare parts. This may also prove difficult given the age and relatively small numbers of machines produced, especially for formats where there was potentially only one model of recorder ever manufactured (such as the Quasar VR-1000 for the VX format). Some success has been achieved in the reverse engineering and machining of parts. An example is the engineering team

75 See the "Akai VT-300" section of the *TotalRewind* website (TotalRewind: n.d.), http://www.totalrewind.org/portable/Q_VT300_main.htm, accessed 11 December 2017.

76 See the "Tapes Page" section of the *Betacam PALsite* website (Barnett and Evans: n.d. [a]), http://betacam.palsite.com/tapes.html, accessed 11 December 2017.

of the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS) successfully recreating new slip disk and brush components for the V-Cord system. The more widespread formats such as Betamax and VHS were licensed to several other manufacturers, and as such, second-hand machines are still readily available in most places around the world and in all major world television standards.

Several different alignment tapes and jigs are needed in order to carry out a full playback alignment. There are no new test tapes available for purchase, and second-hand instances may have been subjected to previous high use and should be used with caution.

Although not ideal, test media can be locally produced, provided a machine can be assessed as still able to make reliable recordings. In section D.1.3.1.4.4.4, this category of test tape is termed *house-made (or third party) VTR alignment and calibration tape*. Playing this house-made alignment and calibration tape in transfer situations can assist technical staff in assessing the day-to-day performance of a machine and double-checking when a playback problem arises with a collection item. Locally produced test tapes can also provide an everyday alternative to the use of rare and expensive calibrated tapes that can be reserved for longer term maintenance purposes. Suggested content for a house-made VTR alignment and calibration tapes includes:

- Video: 100 percent flat field for tracking checks and adjustments
- Video: 5- or 10-step staircase signal for linearity checks and adjustments
- Video: Multi-burst for checking and adjustments of the frequency response
- Audio: Tone series including 125 Hz, 1 kHz (reference level), 3 kHz (speed), and 10 kHz (azimuth)

Test signals should be electronically produced; the copying of an existing tape will introduce errors and distortion. SMPTE or EBU colour bars along with 0VU audio tone are usual test signals. A grey field and silence is also useful for assessing noise levels. HiFi audio must also be recorded along with the linear audio track if supported by the format.

C.6.7 Alignment of ½-inch VTRs used for playback

C.6.7.1 Correction for sub-optimal transfers caused by misaligned equipment

Obtaining an optimal once-and-for-all transfer of the tape is the aim of any digital video preservation process. Only after the playback machine has been satisfactorily set up and aligned with test media (if available), can the first section of a collection item be played back and whatever adjustments available on a consumer machine made. Any electronic on-screen displays should be turned off to prevent them from being captured along with the desired content.

Video-head tracking is a control available on almost all the formats mentioned (except V2000), which manages tracking automatically. The tracking control should be adjusted for the least amount of noise on the picture and on the HiFi tracks, if present. If an industrial or semi-pro machine is used, there may be a tracking meter available that indicates when maximum RF level has been obtained, and also indicates where a tape may have a reduced signal level recording.

It is possible that a very badly produced recording has tracking that varies throughout the tape. In this case, a machine with auto-tracking may provide more stable playback. Later VHS and possibly Betamax machines had this feature. Alternatively, the tape may have to be transferred in sections and re-joined in the digital domain, or via minute manual adjustments during the transfer.

In the case of very poor tracking, either produced by a very bad set up or worn recording machine, the best possible playback may be obtained by deliberately misaligning the VTR to maximize the gain. This should only be done by a trained engineer, and only if the means exist (e.g., alignment tapes or manuals) to return the machine to the correct alignment afterwards. The adjustment may even involve the deliberate misalignment of tape path guides and should only be applied with caution and consideration for whether the modification can be corrected to return the playback machine to normal working order.

Even a well-calibrated playback machine may produce video levels that are out of range for modern digital video systems. Normal broadcast video levels of 0.7V are accommodated in digital systems with some degree of headroom, but excessive domestic video levels will be clipped in the digital domain if they are not controlled in some way. It may be possible, depending on the digitising system in use, to adjust video levels (black, gain, and chroma) at the analogue input to the system. This is a processing amplifier function, usually only available as part of a time base corrector. However, it is important that the controls are effective on the analogue input and not in the digital domain or on the output (as is often the case). Alternatively, a small modification can be made to the machine to allow user control of the playback level alignment.

The use of time base correctors is covered in TC-06 in sections C.4.3.3.1 and C.4.4.3.1 (similar wording pertaining to 1-inch tape types B and C) and C.5.1.2 (U-matic tapes). These sections all offer insights into the importance of cautious and informed use of the TBC enhancement features, such as luma or chroma noise reduction and dropout compensation. Readers preparing to digitise ½-inch consumer and semi-professional tapes are encouraged to consult those sections.

The successful transfer of unstable ½-inch recordings may depend upon the use of an external TBC. Consumer decks, often built to relatively loose tolerances, may produce images with severe instabilities in the output signal that cannot be accommodated by the digitising system. These can be corrected by a high-quality TBC without significantly degrading the image, as long as it is correctly set up. However, attention needs to be paid to the video delay, which may cause a synchronising problem with the audio. Ideally a digital (SDI) connection ought to be used to link the TBC and the digitising system in order to avoid an additional digital-analogue-digital conversion which produces an inevitable reduction in signal quality.

C.6.7.2 Correction for sub-optimal transfers caused by carrier degradation and storage artefacts

After the transfer of the content from the carrier, many faults may still exist in the digital surrogate. Some of these shortcomings may be a result of the low standards applied to the system design and the original recording methods. Others may be a result of carrier degradation and poor storage. The correction of most of the resulting faults is not an archival process, and belongs in the realm of restoration; indeed, an archival transfer facility may not contain the necessary tools to carry out these processes.

Correctable problems may include:

- Excessive dropouts
- Luma noise
- Chroma noise
- Visible head switch points approximately five lines from bottom of image (usually present in consumer recordings)
- Low chroma level
- Chroma phase errors
- Y/C timing errors

More difficult problems include:

- Digital capture artefacts from poor analogue video signal stability
- RF patterning
- "Ringing" on picture edges from poorly designed sharpening circuits
- General luma and chroma softness

C.6.8 Time code for ½-inch consumer and semi-professional videocassettes

Most of the half-inch analogue consumer formats were never designed to accommodate time code, and no consumer formats have a dedicated time code track on the tape. However, in its later years, as VHS became a medium for offline editing, users began to record linear time code (LTC) on one of the audio tracks. Some manufacturers, notably Panasonic, facilitated this by providing a pre-set EQ and automatic level optimised for time code on channel 2. If the user needed to record time code, this could be selected on the front panel, cutting audio from the channel 2 output connector and routing it to the time code output. Some machines were also equipped with a built-in time code reader accessing the LTC on audio channel 2 and providing time code on the 9-pin serial remote connector. If a tape with time code on an audio channel is encountered, provision needs to be made to transfer this as part of the archival transfer.

C.6.9 Time factor for transfer of ½-inch consumer and semi-professional videocassettes

Time taken for transfers will vary enormously depending on format. For some of the more obscure formats, sourcing a suitable machine and bringing it back to a usable condition could take several months, with only one tape transferred at the end of the process. Other formats, such as recent VHS may take as little as 1–2 hours per hour of running time. As mentioned, with consumer formats it may be necessary to audition the transfer in several different replay machines, in order to achieve the optimal result. Checking what options are used in the recording, such as HiFi sound tracks or time code, and configuring the necessary items in the replay chain all add to the transfer time. Particularly problematic tapes may need to be transferred in segments and re-joined in the digital domain. As such, it may only be possible to extrapolate a time factor after a project has been under way for some period of time.

C.7 BETACAM ½-INCH PROFESSIONAL VIDEOCASSETTE FAMILY

C.7.1 Introduction

The Sony Betacam format was introduced to the marketplace in 1982 and is commonly referred to by the original format name: *Betacam*, a term that is used in a generic sense for the variety of Sony Betacam devices that use ½-inch magnetic tapes housed in the same types of cassette shells. Better thought of as a seven-member *format family*, the marketplace has seen several Betacam iterations, including two in analogue form, Betacam, Betacam SP, and five digital, Digital Betacam (DigiBeta), Betacam SX, MPEG IMX, HDCAM, and HDCAM SR.

The format was introduced not long after the format war between Betamax (SONY) and VHS (JVC),[77] as described in the sidebar that follows section C.6.4.8.3. Aimed at professionals, Betacam was the successor of the SONY and Ampex VTR formats of 1-inch and 2-inch magnetic tape video recorders and more directly replaced the U-matic range of professional video recorders introduced in 1971.[78]

All of the Betacam family members offer a high-quality video recording format and have been used professionally within the broadcast and video production industry. The original analogue Betacam was the preferred format for professionals and was extensively used throughout the 1980s and 1990s. It was produced in both a small and a large cassette, with the smaller cassettes used for portable, camcorder capture and the larger tapes for longer recordings, generally in more static shooting setups. The smaller tape cassettes have the same form factor as the SONY Betamax format and are easily confused. Other variants of the cassettes can also be hard to distinguish. When Betacam was first released, it and Betamax recorded on the same ferric oxide tape formulation in the same cassette shell, and even the audio tracks were physically in the same place on the tape. The recording formats, however, are different and not interchangeable.[79]

There were many different versions of Betacam, from the earliest analogue tapes to robust digital tapes for camera work and an extensive range of developments in between. Though the form of the cassette remains predominately constant through the life of the format, the tapes were recorded in each Betacam format according to quite different standards and approaches and the different versions are often incompatible.

C.7.2 Selection of best copy

Betacam, as the successor to 1-inch type B and C, and U-matic, was used in all areas of video production from capture to master, and even as an interim storage format in many archives and collections. It was used on its own, and in projects involving multiple media types, often in parallel with other formats and carriers. For this reason, the first decisions about selection of best copy are curatorial, i.e., the curator's determination of what is in scope for preservation and what content is the most significant. Some archivists will select the master version, as representing the final work, while others will select the original footage, presumably for the subject matter, and many will select both the final masters and the footage "as shot".

After the categorical decisions have been made, the curator will check the archive's holdings and identify the best copy within each category, i.e., the copy that carries the most complete and highest quality information. This assessment may take advantage of

77 See the "Format" section of the *Betacam PALsite* website (Barnett and Evans: n.d. [a]), http://betacam.palsite.com/format.html, accessed 11 December 2017.
78 Wikipedia, *Betacam*, https://en.wikipedia.org/wiki/Betacam, accessed 6 September 2016.
79 Wikipedia, *Betamax*, https://en.wikipedia.org/wiki/Betamax, accessed 6 September 2016.

labelling or other written documentation, or it may depend upon additional findings that describe the creation of the copies at hand. Where there is no curatorial path or clear provenance to determine the most original recording, the cassette or carrier may provide clues. The curator may additionally judge the quality of the recording, and/or assess the condition and playability of the videocassette, since these factors may influence playback quality.

In the case of analogue recordings, as a rule, the earliest recording in terms of copy *generation* will provide the best playback quality. That is, all other things being equal, a duplicate (or duplicate of a duplicate, and so on) will exhibit inferior visual characteristics to a tape from an earlier generation. Successive analogue copies typically suffer from generation loss, i.e., degradation of image quality, loss of accurate tracking, and the like. In the case of digital recording formats this factor is less significant as well as being more difficult to determine, depending on the method used to duplicate the content prior to its arrival in the archive.

Video recordings in an archive may have been manipulated in prior duplication actions. For example, there may have been changes in the underlying resolution (pixel counts) or aspect ratio. We recommend that archives seek to determine and maintain a recording's original "native" resolution and aspect ratio (i.e., the resolution and aspect ratio that resulted from the original creative process). If a recording exists natively in high definition (HD), this is a preferable digitising source to a standard definition (SD) version. In assessing some of these features, archivists may be able to take advantage of the general descriptions of various Betacam formats provided in the subsections that follow. These descriptions may also serve as a guide to compatibility, age, and technical quality in the selection of the best copy.

An inferior tape would only be selected when there is no alternative and making this selection enables the capture of more content than may be obtained from a tape that is superior in theoretical terms but may be physically damaged or unplayable.

It is always advisable to play back material on more than one VTR as this can aid decisions regarding the best way to transfer, and to identify a given tape's audio track configuration. Auditioning allows the determination of the characteristics of the recordings such as whether there is noise reduction.

The Betacam format family served professionals, including broadcasters, and tapes now held by archives may exhibit overt or covert issues that resulted from their creation in fast-turnover, time-dependent workplaces. Tapes may include multiple and/or discontinuous time code, or feature residual segments resulting from tape-over. Tapes from a production environment may have been re-used multiple times and contain fragments from other productions, video feeds or cameras, with or without a time code. Determining how and what to transfer from these tapes will require a mixture of curatorial decision-making and technical expertise in revealing information about the creation of the recorded content, and in determining the best pathway. Pragmatic considerations also play a role: an archivist may decide that it is more cost effective or efficient to transfer entire tapes without selection and leave the decision about content to the future, or to an end-user. This, of course, raises ethical and curatorial issues that would need to be weighed regarding the right to take this approach, given that multiple original content creators may be involved.

C.7.3 Typology of Betacam formats and replay equipment (playback VTRs)

C.7.3.1 Betacam

The VTRs that recorded the original Betacam format were analogue, utilising four heads to record. The signal's colour space is colour-difference component, consisting of one luma channel (Y') and two chroma channels: one that carries the difference between blue and luma (B-Y, or PB), and another that carries the difference between red and luma (R-Y, or PR). Strict terminology for analogue colour-difference component is *Y'PBPR*, often loosely referred to as *YUV*. This format also includes stereo, frequency-modulated audio tracks and is considered a low-band Betacam format. The early Betacam units utilised only a ferric oxide tape at two different lengths, S (30 minutes) and L (90 minutes).

The initial Betacam was replaced with the Betacam SP (Superior Performance) format which is one of the most common in the range. The replacement signalled the departure from ferric oxide based tape to a metal oxide tape to achieve greater performance through increased carrier and deviation frequencies.[80]

C.7.3.2 Betacam SP

Betacam SP presented enhanced features and performance when compared to the original Betacam format. The VTRs for this format introduced such technologies as a built-in longitudinal time code generator (LTC) and reader, built-in time base correction (TBC), and the later models included multiple (i.e., four) audio channels and introduced the use of DOLBY-C type noise reduction. The recording method uses a frequency modulated luma, time division multiplexing/time compression for chrominance, and frequency modulated chrominance channels respectively. Some models included dynamic tracking and vertical interval time code (VITC) and some Betacam SP VTRs support the playback of Betacam format tapes.

Betacam SP tapes are commonly metal in recordable lengths of S (30 minutes) and L (90 minutes). Tape speed is slightly slower in machines working in the 625/50 format, increasing tape duration of one minute for every five minutes of run time. Thus, a tape rated as 90-minutes for NTSC will record 108 minutes of video in PAL.

C.7.3.3 Digital Betacam

Digital Betacam, generally referred to as DigiBeta, is the first format in the Betacam range to adopt digital recording in the D-1 format.[81] The underlying picture data is recorded with 4:2:2 chroma subsampling[82] and 10 bits per sample. The recording uses discrete cosine transform (DCT) to achieve 2:1 compression. DigiBeta PAL resolution is 720x576; NTSC resolution is 720x480. The bitrate is 90 Mbit/s and the video bandwidth and sampling frequency are far greater than the analogue Betacam formats. There are five audio channels: four digital channels, recorded at 48kHz and 20 bits per sample, as well as one analogue cue track. Digital Betacam VTRs can play Betacam SP Tapes.[83] Some Digital Betacam VTRs have the option to play analogue Betacam Cassettes.

Digital Betacam tapes are commonly in recordable lengths of S (40 minutes) and L (120 minutes).

80 See the "Format" section of the *Betacam PALsite* website (Barnett and Evans: n.d. [a]), http://betacam.palsite.com/format.html, accessed 11 December 2017.
81 Wikipedia, D-1 (Sony), https://en.wikipedia.org/wiki/D-1_%28Sony%29, accessed 6 September 2016.
82 Wikipedia, *Chroma subsampling*. https://en.wikipedia.org/wiki/Chroma_subsampling, accessed 6 September 2016.
83 See the "Digital Betacam" section of the *Mediacollege.com* website (Wavelength Media: n.d.), http://www.mediacollege.com/video/format/beta/digital-betacam.html, accessed 11 December 2017.

C.7.3.4 Betacam SX

Betacam SX is a digital version of Betacam SP introduced in 1996. It utilises 8-bit MPEG-2 4:2:2 compression with four channels of 48 KHz, 16-bit pulse code modulation (PCM) audio. This format was the first to employ the MPEG-2 compression algorithm capable of outputting high-quality pictures at a relatively low data rate of 18 Mbit/s. Additional features included dynamic motion control, error correction coding, serial data transport interface (SDTI), SX interface for external MPEG connectivity of compressed data, and compatibility with legacy Betacam/SP playback (Sony: 2000 and Sony: 2001).

Betacam SX tapes are commonly in recordable lengths of S (62 minutes) and L (194 minutes).

C.7.3.5 MPEG IMX

MPEG IMX is a 2001 development of the Digital Betacam format. The format was introduced when SMPTE issued two standards on which MPEG IMX is based.[84] The first of these (SMPTE ST 356) specifies a particular H.262/MPEG-2 Part 2 video stream: 422P@ML (4.2.2 chroma subsampling *profile* at main *level*), with an intra-frame compressed video signal, i.e., "all I-frame" encoding with no temporal inter-frame compression.

Depending on the compression setting, D-10/IMX streams can be encoded at data rates higher than Betacam SX, with resulting superior quality. D-10/IMX digital video compression offers data rates at 30 Mbit/s (6:1 compression), 40 Mbit/s (4:1 compression) or 50 Mbit/s (3.3:1 compression). The video payload also includes up to eight channels of audio and a time code track. Although our focus here is on videotape recording, it is also possible (and today, it is more widespread) to record the D-10 stream in file form, carried either in a MXF wrapper or as an .mpg (MPEG) file.

Some MPEG IMX devices can record as many as eight channels of 48kHz 16-bit digital audio or can be switched to provide four channels of 48kHz 24-bit audio.[85]

The IMX format offers long recording times, depending upon tape size, as much as 220 minutes on the larger cassette and 71 minutes on the smaller. Some IMX VTRs are able to play Betacam SP/SX and Digital Betacam videocassettes.

C.7.3.6 HDCAM

HDCAM, introduced in 1997, was the first HD format available in Betacam. HDCAM uses an 8-bit, 3:1:1 discrete cosine transform (DCT) compression recording compatible with 1080i, it is down-sampled to 1440x1080 (non-square pixels) and then up-sampled to 1920x1080 (square pixels) resolution on playback. The bit rate is 144 Mbit/s and audio may include as many as four channels of AES3 sound at 48kHz 20bit. This format employs the SMPTE 367M *aka* SMPTE D-11 Standard for HDCAM which specifies the compression and resolution of HD video.[86] HDCAM SR (superior resolution) uses a higher particle density tape and is capable of recording in 10-bit 4:2:2 or 4:4:4 RGB with a video bit rate of 440 Mbit/s, and a total data rate of approximately 600 Mbit/s.[87]

84 SMPTE standard ST 356:2001 (Archived 2006) Television – Type D-10 Stream Specifications – MPEG-2 4:2:2P @ ML for 525/60 and 625/50, and SMPTE standard ST 365:2001 (Archived 2006) Digital Television Tape Recording – 12.65-mm Type D-10 Format for MPEG-2 Compressed Video - 525/60 and 625/50.

85 Wikipedia, H.262/MPEG-2 Part 2, https://en.wikipedia.org/wiki/H.262/MPEG-2_Part_2, accessed 6 September 2016.

86 Wikipedia, *HDCAM*, https://en.wikipedia.org/wiki/HDCAM, accessed 6 September 2016.

87 Ibid.

HDCAM VTRs enable universal playback of ½-inch Sony formats from Betacam to MPEG IMX and are widely used in HD television today as they provide a down-converted SDI output for HD recording and an up-converted HD SDI output for other formats. HDCAM (SR) VTRs could only play HDCAM and Digital Betacam as an optional extra.

C.7.3.7 HDCAM SR

HDCAM SR, introduced in 2003, uses a higher particle density tape. HDCAM SR format cassettes are not compatible with standard HDCAM as they are of a different specification. The SR can achieve a video resolution of 1920x1080 without down sampling and has several conversion capabilities. The bitstream actually laid down on the tape is compressed using the MPEG-4 Part 2 Simple Studio Profile;[88] it is decompressed when the tape is played. There is a broad range of format conversion built in to HDCAM SR models like the SRW-5000 where the VTR can perform down conversion from 1080 to 525 or 625, 1080 to 720p, or 720p to 525, and up conversions from 525/625 Digital Betacam to 1080, 720p to 1080 or 525 Digital Betacam to 720P.

The HDCAM SR standards are 1920x1080 or 1280x720, sampling at 4:2:2/10-bit or 4:4:4/10-bit with frame rates of 23.98, 24, 25, 29.97, 30 FPS - 50, 59.94, 60i FPS (1920x1080) or 59.94FPS at 1280x720 (4:2:2 only) (Sony: 2004).

The HD CAM series may have been the final appearance for the ½-inch Sony Cassette/Betacam format. It was an extremely high-quality device; however, the cost of the VTRs and stock inhibited large broadcast take up, and by this stage storing digital video on commodity hardware was becoming more commonplace, and format specific tape outmoded.

Outputs are commonly BNC type COAX connectors for SDI, component, and composite. Audio connectivity is generally through embedded SDI but can also be connected through dedicated XLR connectors.

C.7.4 Compatibility of Betacam videocassette types on different Betacam VTRs

The earliest machines in the Betacam range were purely analogue so playback of later digital and high-band recordings is not possible, likewise the number of channels and format or audio channels will differ on the models over the years, so new tapes cannot usually be played on older machines. However old tapes can be played in a range of newer playback devices. Sony has maintained a relatively good level of backward compatibility throughout machines over the years and this is mostly consistent with at least the current model at the time being able to play tapes from the former, or discontinued model.

88 The relevant standard for the ITU-T H.263 compression encoding is *ISO/IEC 14496-2:2004, Information technology -- Coding of audio-visual objects -- Part 2: Visual.* This standard includes specifications for a number of profiles. In many applications, ITU-T H.263 compression has been supplanted by ITU-T H.264 (aka *AVC*) and standardized in *ISO/IEC 14496-10:2014 Information technology -- Coding of audio-visual objects -- Part 10: Advanced Video Coding*, which also specifies a number of profiles. Additional profiles are specified in other documentation; see Wikipedia *H.264/MPEG-4 AVC* heading "Profiles," https://en.wikipedia.org/wiki/H.264/MPEG-4_AVC#Profiles, accessed 11 December 2017.

C.7 Table 1. Backward Compatibility of Betacam VTRs

Tape format	Original format machines will play
Betacam	Betacam
Betacam SP	Betacam, Betacam SP
Betacam SX	Betacam, Betacam SP, Betacam SX
Digital Betacam	Betacam, Betacam SP, Betacam SX, Digital Betacam
MPEG IMX	Betacam, Betacam SP, Betacam SX, Digital Betacam, MPEG IMX
HDCAM	Digital Betacam, MPEG IMX, HDCAM
HDCAM SR	HDCAM, HDCAM SR (Digital Betacam with Option)

Tape type, if compatible, may have some impact on signal delivery and early model machines should be tested when available. Late model digital machines have a capability to detect an analogue tape and adjust the TBC depending on the tape. Different tapes have a different track size and depending on the head spin have a larger diameter or track length and level of RF (Radio Frequency) that is coming from the tape. Analogue tapes will have a shorter or smaller diameter. Analogue time difference can be compensated for as head drum is a different size on different machines, the TBC can adjust this via signal processing to perform the best playback for the tape. If a digital Betacam tape is inadvertently played on an early analogue machine, it will most likely reject the tape.

Different playback devices can affect playback based on the way they pass the video information through the machine. Some devices, while being analogue in nature, will have digital elements that control the way the signal is reproduced; e.g. some machines perform better in terms of dropouts and recovery, newer devices such as BVW series and onwards will reduce or remove dropouts by use of an inbuilt TBC. The TBC converts the analogue signal to digital and in the BVW range the signal is adjusted in the digital domain, the later machines perform this process better as they have larger memory buffer to do so. It is important to look at the signal output quality and compare that against that specification and compare on different machines. Likewise, an older tape may perform better in an early model Betacam device that exhibits similar analogue settings and alignment.

The replay of some cassettes may be enhanced if their alignment mirrors the alignment of the deck used to record the material. However, a machine out of alignment will not perform to the best of its specification and should be set to standard alignment for best practice. Still, having a range of machines with minor adjustments to the tolerances can provide options for paying back a cassette with issues.

C.7.5 Availability of Betacam VTRs

The Betacam family of machines was a long-lived and popular format, and its use continued into very recent years. For these reasons Betacam machines are still readily available on the second-hand market. However, the comprehensive use by broadcast companies and archives, including as a storage media, means there is an equally high demand for this equipment. Parts are difficult to source and many of them are specific to the machine, so even the later Betacam machines have become difficult to maintain.

C.7 Table 2. List of Betacam VTR models

Betacam Machines:	
Sony Beta (non-SP):	
	BVW-10 (playback only, transport for a/b rolls to VTR, with TBC)
	BVW-15 studio player
	BVW-20, BVW-21, BVW-25 (Field playback deck)
	BVW-40 studio edit recorder
Sony Betacam SP Machines:	
	BVW-22 (logging/viewing only)
	BVW-35 (field recorder)
	BVW-50 (field recorder, 90min cassettes, digital audio)
	BVW-60 (SP VTR)
	BVW-65 (features dynamic tracking)
	BVW-70 (edit/record)
	BVW-75 (edit/record, dynamic tracking)
	BVW-600
	Metal formulated tape, over ferric oxide, forward compatible, playback only (Betacam), a 90-minute tape will record 108 minutes of video in PAL.[1]
'Industrial' Betacam Machines: (early 1990s) Less expensive "Professional" PV series:	
	PVW-2600
	PVW-2650
	PVW-2800. (mid-1990s) (widely used for RS422 and full featured)
	UVW-1600, -1800 series.
	2000 MSW-2000 - VTR (MPEG IMX format) capable of storing video data of up to 50 Mbps through the use of MPEG2 compression technology.
	HDCAM
	HDW-2000
	HDW-S280/1
	JH1/JH-3
	PDW-F1600
	HDW-F500
HDCAM SR	
	SRW-5100 (HDCAM SR) playback only device, optional HDCAM and Digital Betacam playback
	SRW-5000 (HDCAM SR) Recording + HDCAM Playback, and optional Digital Betacam playback
	SRW-5500 (HDCAM/SR, HDCAM) Recording/Playback, and optional Digital Betacam playback
	SRW-5800 (HDCAM/SR) Recording/Playback, optional HDCAM and Digital Betacam playback

1 Wikipedia, *PAL*, https://en.wikipedia.org/wiki/PAL, accessed 11 December 2017.

C.7.6 Betacam videocassette types and tape formulations

Magnetic materials manufactured over the past 50 years have used polyethylene terephthalate (PET) for tapes with binders (oxide, and MP tapes) and polyethylene naphthalate (PEN) for metal evaporative tapes. Betacam tapes 1986–89 used the former *Ferric Oxide* material; this was a different compound from the small iron particles found in *Metal Particle (MP)* tapes (Sony: 2009, p. 1) used in Betacam and Digital Betacam cassettes.

C.7 Table 3. Types of Metal Betacam Videocassettes

Betacam SP: 1 /2-inch cassette Metal tapes:	
	BCT-5M/10M/20M/30M
	BCT-5ML/1OML/20ML/30ML/60ML/90ML (Sony: n.d. [b])
	UVWT-10MA/20MA/30MA
	UVWT-60MLA/90MLA (Sony: n.d. [c])

C.7 Table 4. Types of Betacam Videocassettes grouped according to size

Small outline tapes	
	Fujifilm
	Sony Betacam-SP. Sony BCT-10MA SP, 256ft, 78m.
	Sony BCT-20G 492ft (150m) back coated.
	Sony BCT-5MA, BCT-20MA SP, 492ft, 150m, back coated
	Sony BCT-D6, BCT-D12, BCT-D32, BCTD40
	Maxell MXB-10MSP, MXB20MSP, MXB30MSP
	Maxell B-20MSP. Maxell MX-B62SX
	Maxell BD-22, BD32, BD40
Large outline tapes	
	Ampex 398 SP, metal tape, Large tape
	Sony BCT-60MA, BCT-xxMA, Large tape
	Sony BCT-60MLA. BCT-xxMLA SP, Large tape
	Sony BCT-D64L, BCT-D94L, BCT-D124L
	Maxell MX-B90MK SP. Maxell MX94SXL
	Maxell BD-22, BD32, BD40, Large tape

C.7.7 Maintenance of Betacam-family VTRs

Tape machines need to be carefully aligned to match factory specifications for optimal transfer; tolerances for such adjustment are quite small and need to be monitored regularly. Tape cleaning and restoration will enable a well aligned machine to retrieve the best quality signal.

Playback devices should be cleaned and maintained regularly to assure they are performing within specification. Cleaning of the video and audio heads requires a specific cleaning cassette that is played in the machine to perform drum cleaning; there are cleaning tapes available for each series of Betacam playback devices. Such cassettes are hard to find but can sometimes be purchased online.

C.7 Table 4. Special Videocassettes for cleaning Betacam family VTRs

BCT-5CLN: Betacam, Betacam SP, Digital Betacam (Sony: n.d. [d])
BCT-D12CL: Digital Betacam[1]
BCT-HD12CL: HD Cam (Sony: 2012)
PDVM-12CL, PDV-12CL: DV Cam (Sony: 1999)

1 *Sony BCT-D12CL* is described by the vendor Tapeonline.com, https://www.tapeonline.com/products/sony-video-cleaning-tape-bct-d12cl, accessed 15 December 2017.

Cassettes designed for VTR cleaning have limited use, usually the length of the cassette. Cleaning should be performed in playback mode for a limited time period and if five cleaning attempts do not solve the problem, VTR servicing is recommended. For specific problem details consult service manual or a qualified technician.

Cleaning of the heads can be performed most effectively by hand using either a chamois or lint free tissue moistened with isopropyl or other approved head-cleaning product. Clean the heads by rotating them and lightly pressing the cloth against the head drum. Clean the heads until the tissue is not wiping off any oxide. Never move the cloth vertically up or down as this can break the heads. Clean the tape path including the audio heads, erase head, tape guides, and rollers, and demagnetise the audio heads. Clean compressed air is also useful for removing dust and oxide from the internal workings of the VTR.

Regular usage of VTRs keeps them fit, and we recommend continuous use. If a machine is likely to be offline for a period of time then a schedule should be implemented that exercises its mechanical parts on a regular basis. Resurrecting a damaged or unused device is often harder than maintaining a working device.

Regular use will sustain movement to important parts in the device that can be prone to failure. Betacam machines contain many moving parts and lubrication points that need to be continually stimulated. Irregular use can cause grease to bind, rendering moving parts immobile. Cleaning and lubrication of moving parts should be part of the regular service schedule for all devices in use.

Betacam VTRs have a usage meter that can display run time, usually in units of 10 hours. The display of the machine operation hours, drum rotation, tape run time, threading and other meters can be displayed to view the usage of a device. This can be useful to schedule cleaning and maintenance.

Maintenance planning should take note of the availability of personnel with the skills and knowledge to perform specific maintenance within local networks; such skills are a difficult balance of mechanical and electrical engineering that comes from prolonged experience with this type of device.

Common technical issues can be traced to a faulty or worn part within the VTR. The most common parts to fail are pinch rollers, fans, lamps or moving parts such as switches. Other failure-prone parts include the upper and lower drum (Sony), also known as the Scanner (Ampex), belts, treading motors, capstan motors, and reel motors. Generally speaking, motors will continue to function for a long time.

Keeping a selection of parts on hand for machines is difficult as parts for early Betacam technology have become virtually impossible to find. Video and audio heads are a common replaceable part and could easily be one of the most important to keep. Historic Sony professional recorders are expensive for a reason; they are generally hard wearing and perform for many years with minimal in-depth maintenance.

Thus, parts availability is the biggest consideration for maintaining Betacam VTRs. Several Betacam machines are rare and finding ways to maintain them can be difficult. Service and replacement of consumables like pinch rollers, belts and drum assembly can be difficult with limited resources as often parts are limited. An awareness of this difficulty has led both archives and production organisations to stockpile parts in an occasionally competitive manner.

Meanwhile, regarding the most recent models, Sony officially discontinued manufacture as of March 2016, with a commitment to servicing until March 2023.[89]

C.7.8 Alignment of Betacam-family VTRs

C.7.8.1 Normal alignment, calibration, and related actions

Alignment should be performed by a qualified technical engineer to a standard or specification published by the manufacturer and/or an audiovisual-industry trade organisation. For example, the EBU has published documents on Betacam SP alignment tolerances (EBU: 1992b).

As described below, several Betacam VTRs can perform self-alignment, particularly the digital based models. However, as new parts are often no longer available for the commonly replaced components, such as belts, brake pads, and other consumable components, replacement parts will either be second hand, or generic. Worn or non-standard parts will have an impact on the self-alignment capability of the machines. Consequently, alignment of the playback machine should follow the prescribed technical procedure in the service manual and may require manual mechanical or electronic adjustment.

All experts recommend the use of test tapes to calibrate Sony Betacam VTRs. Ideally, these would be from the category termed *manufacturer VTR alignment and calibration tapes* in section D.1.3.1.4.4.3. In the earlier devices, calibration required much manual intervention; with the later VTRs most of the calibration is performed automatically. A standard piece of maintenance equipment for the devices that require manual adjustment is an *extender board*. The densely packed electronic devices do not allow adjustment in situ. An extender board enables the machine to run while the components under adjustment are outside of the machine. Although once a part of the maintenance technician's kit, these vital items were rare and are now very difficult to find. Digital

89 Sony Corporation (Australia), 2016. *Sony announces sales discontinuation of 1/2 inch VTRs and camcorders* (press release), https://pro.sony.com.au/pro/article/broadcast-products-vtr-announcement, accessed 15 December 2017.

machines require a test tape but can self-align. All the Betacam family VTRs use format specific test tapes.

Manufacturer VTR alignment and calibration tapes for historic machines are no longer produced and are hard to find second hand. They are used to adjust playback and record settings from the video head to the output, test tapes are generally the only device used for restoring alignment to factory settings. Machines will be set up for NTSC or PAL and checked for alignment periodically.

Head replacement is a major service action for any VTR. Engineers who install new heads in analogue Betacam machines employ manual test points to check settings. It is the case that, once replaced, heads are generally correctly positioned and aligned to the extent that the auto-alignment capability can make the necessary fine adjustments. Installing new heads in digital Betacam VTRs requires a digital test tape that the VTR uses to align itself. The technician replacing the heads must navigate the digital VTR controls to a sub-menu to launch the automatic self-alignment process, which uses built-in motors to adjust the head's skew and phase.

Other adjustable parameters like radio frequency (RF) utilise a user adjustment for tracking, which can usually be accessed from the front panel.

Another technical adjustment is made by using an eccentricity gauge, which enables adjustment for the mechanical setting of the head. This gives an indication how out-of-round the head is and supports making adjustments to the correct alignment and eccentricity. Such processes should only be attempted by a skilled technician.

C.7.8.2 Testing, maintenance, and playback with some do-it-yourself actions

It is possible to create a "testing cassette" on an aligned machine to check the alignment of another machine when troubleshooting. This can highlight issues in a helpful way, but this does not produce a calibration tape: problems may be revealed or confirmed but no adjustment of the VTR will have been made.

Meanwhile, if Betacam videocassettes from an archive's collection do not play back properly, the technician may have observed issues such as loss of synchronisation lock, missing colour information, and dropouts. If so, it may be difficult to deduce the cause of the problem on a correctly aligned machine. In some situations, however, the technician can employ an incorrectly adjusted machine to play a poorly aligned tape. In order to achieve this outcome, the technician manually tweaks the TBC to improve the output. Making adjustments to the playback machine can enable replication of the *incorrect* picture phase as it was recorded when the alignment was out, and the sub-optimal alignment can reproduce the settings to which it was originally recorded. If controls on the front panel do not enable the user to adjust for a quality picture within their operating range the machine can be temporarily put out of alignment to match a bad tape, this can involve adjustment of the tape path or angle of tape on the head. Care should be taken to restore the original alignment setting after such a process.

Control track longitudinal (CTL) pulses which mark where the video tracks are can be low signal and enter into the range of noise. An approach can be to boost the pre-amp to increase a low-level CTL pulse that may enable re-syncing of the picture.

Later model VTRs capable of playing back multiple formats, such as the J series and HDW series, have a depth of compatibility that enables legacy playback of earlier Betacam formats. This makes them more desirable for digitising than VTR models capable of playing only one format. Most of these less adaptable, single-use devices are earlier models, making the spares for them even more scarce. Therefore, archives should try to cover as many bases as possible by inventorying one or more multiple-format playback machines in order to diminish compatibility issues and minimise upkeep of devices.

C.7.9 Sound tracks

Analogue and digital sound with a range of inputs and outputs can be found on various Betacam VTRs. The earlier Betacam and Betacam SP units generally have analogue audio, with digital audio available from the Digital Betacam and later models. The Digital Betacam units also provide a cue track for analogue audio alongside four channels of digital audio.

Betacam generally carried two channels of linear analogue audio tracks, often with Dolby type C noise reduction. Betacam SP has four channels of analogue audio, via four XLR connectors. Some playback devices feature Dolby C noise reduction and are frequency modulated (FM) audio. Early versions of Digital Betacam saw the introduction of digital audio on four main channels and one cue track, with the digital signal at 48kHz with18- to 20-bit sampling. Later models offered as many as eight audio channels (four AES pairs), 48khz with 20- to 24-bit sampling, compatible with the AES3 Standard.[90]

Newer machines will have up to 12 channels of audio playback, this is delivered at a lower bit depth than using four channels. Likewise, older BVU machines might have two channels or four and some machines have four channels of digital audio and one analogue cue track. On newer tapes, there may be surround sound mix-downs in 5.1 or 7.1 format and such formats will need to be transferred as unique channels to preserve the nature of the soundtrack. The variety of possible standards requires that correct selection of the playback device is necessary to ensure all audio material is transferred.

Contemporary digital works that include such audio formats as stems, DME (dialog, music, and sound effects), and surround sound may use structures or settings that are specific to a given production. The tape may include audible tones (-18.00dBu or 0.0dB) that are intended for equipment alignment. These special cases require special care when digitising.

C.7.9.1 Noise reduction

Dolby C noise reduction is present on early model Betacam and Betacam SP VTRs. At the time noise reduction was popular when recording an analogue signal, and many tapes may carry Dolby-encoded audio. Use of Dolby C when digitising or transferring cassettes that feature this encoding is important since it will greatly affect the output signal equalisation and bandwidth.

C.7.10 Time code on selected Betacam-family videocassettes

Digital Betacam units can have two types of time code: LTC (Longitudinal Time Code, aka Linear Time Code) and VITC (Vertical Interval Time Code). The benefit of VITC is it permits the VTR operator to shuttle the machine transport to a subframe and check levels without a break in the continuity of time code. LTC will only work in real time and can cause issues for playback and synchronisation of devices. LTC is present on early model Betacam units.

90 Wikipedia, *AES3*, https://en.wikipedia.org/wiki/AES3, accessed 7 September 2016.

C.7.11 Time factor for transfer of Betacam-family videocassettes

The process of digitisation for professional ½-inch tapes can vary greatly depending on the tape, as a general rule expect to double or triple the amount of time for the length of program. There are many stages to the process and a methodical careful approach is advised. Cassettes with any sort of problems will require further attention and can often require intense conservation processes such as several days or more in low-humidity rejuvenation.

For a 60-minute program the following time may be required:

- Tape inspection, condition report: 10 minutes
- Cassette preparation, cleaning: 20 minutes
- Test-replay, alignment, checking: 10 minutes
- Actual digital transfer time: 60 minutes
- Export, file management, transport: 20 minutes