Audio and video carriers

Recording principles, storage and handling, maintenance of equipment, format and equipment obsolescence

Dietrich Schüller

This is a full text version of the Power Point Presentation used by Albrecht Häfner and Dietrich Schüller in training workshops on audiovisual preservation organised as part of the EU Commission Project TAPE. While a modern, comprehensive text on the preservation of audio and video carriers does not exist at present, the principles of the long-term preservation of historic recordings and the practical aspects of the production and preservation of digital audio content are covered in publications produced by the International Association of Sound and Audiovisual Archives (IASA). This text is an advance abstract of a comprehensive document currently under preparation for IASA. It also includes a chapter on the maintenance of equipment and the obsolescence of formats.

February 2008

Edited by George Boston

Contents

Part 1: Type of carriers, recording principles, composition and life expectancy, deterioration by replay

MECHANICAL CARRIERS

Mechanical carriers constitute the oldest commonly used type of carriers used for audio recordings and reproduction. The first recording system was the cylinder phonograph, invented by Thomas A. Edison in 1877 and improved and marketed from 1888 onwards. Originally intended as an office device for dictation purposes, it became popular for scholarly recording of language and ethnic music, for which it was used until the 1950s. Cylinders were also used by the phonographic industries for pre-recorded music. This format, however, was less successful than the gramophone disc and vanished from the market in the late 1920s. Mechanical disc formats governed the market from the late 19th century until the 1980s, when they were superseded by the Compact Disc.

Recording principle

The sound, which is a function of the variation of air pressure, is transformed into movements of a cutting stylus and engraved into the surface of a rotating medium. This was originally done purely mechanically. The sound was captured by a horn, moving a membrane which was connected by levers to a cutting stylus, which engraved these movements into the surface of a rotating wax cylinder or disc. Reproduction worked in the opposite way. A stylus was moved by the modulated groove, driving the membrane via levers, the vibrations of which were amplified by the horn.

Around 1925 this acousto-mechanical process was superseded by an electrically amplified system. In this system, the sound was transformed by a microphone into an electrical signal, which moved an electrically driven cutting stylus. The reproduction was also improved by the use of electrical pick-up systems, the signals of which, suitably amplified, were reconverted into mechanical movements by loudspeakers or headphones. Recently, systems for optical, contact-less replay of mechanical carriers have been developed. These have, however, not achieved wider acceptance. (For signal retrieval from mechanical carriers see IASA-TC 04, 5.2 and 5.3.)

Composition of carriers and stability of their components

Cylinders

With cylinders the groove is arranged across the surface. The modulation of the sound signal is engraved vertically (“hill and dale”).

There are self recorded and replicated cylinders. The first group always consists of “wax” of different chemical compositions. Cylinder replication was possible either by a copying process from masters, which allowed for a limited number of cylinders, or by replication from a galvanoplastic negative. This was a copper tube, which carried the “inverted” groove on its inner surface. These negatives were used to make wax casts or to create celluloid (= cellulose nitrate) positive tubes produced under high pressure steam. The celluloid tube was then supported by a plaster core inserted into the tube to provide stability.

The many wax compositions used for wax cylinders are, if properly stored, chemically fairly stable. Wax, however, is highly susceptible to fungus growths and, as many cylinders have not been stored correctly in their earlier lives, a typical storage artefact is fungus. Celluloid cylinders suffer from brittleness of the cellulose nitrate surface, but catastrophic deterioration as known from nitrate films is not a common experience. Mechanically, all wax cylinders and the plaster cores of celluloid cylinders are extremely fragile.

Coarse groove discs (gramophone discs)

Emile Berliner invented the gramophone in 1887. The grooves are arranged as a spiral on the surface of a disc. Generally, the modulation of the grooves is lateral, as opposed to the vertical modulation of cylinders. Only few disc formats (Pathé, Edison) have vertically cut grooves. The big advantage of the disc shape is that galvanoplastic negatives can be easily made which are used for replication by pressing. As the number of pressings is limited, the first metal negative ("father") serves only as a master for a metal positive ("mother"). This, in turn, is used to produce an unlimited number of metal stampers ("sons") which are used as the pressing tools for the replicated discs. This process, developed at the end of the 19th century, is also used for micro groove discs ("vinyls"), and is still in use for the production of replicated CDs and DVDs.

Replicated coarse groove discs (shellacs) consist of a mixture of mineral powders bonded together by binders, originally containing shellac resin. These materials are chemically generally very stable if kept under fairly dry conditions. They are fragile, however: When dropped, they break.

Instantaneous discs (also called direct-cut discs) are recording media made of a variety of materials. They were wide spread, mainly in radio stations, before the advent of magnetic tape to record and replay signals. The same discs were used for both the recording and the replay without the need for galvanoplastic processing and pressing. Their surfaces are soft enough to permit the cutting of the groove but hard enough to permit a number of replays. Most of these discs are unique recordings.

The most wide spread type of instantaneous discs are the lacquer or "acetate" discs. A lacquer coating, consisting mainly of cellulose nitrate, carries the information. The substrate or support of the discs is generally made from metal but some are of glass. The lacquer coating becomes brittle with age and shrinks, thereby often crazing and flaking off the substrate. Lacquer discs still in apparently good condition may craze at any moment. Such discs should, therefore, be immediately transferred to digital before the sounds become lost. Many other materials including waxed cardboard, zinc, gelatine, etc. have been used for instantaneous discs. All should be considered to be at great risk.

Microgroove discs (LPs, vinyls)

From the late 1940s onward a new material was used for discs. A co-polymer of polyvinyl chloride (PVC) and polyvinyl acetate (PVA) was introduced for two new formats. RCA launched a seven inch (= 17 cm) disc which runs at 45 rpm with a playing time of three minutes per side – the same as the old shellac disc format. Columbia started the 10 inch (= 25 cm) LP, later enlarged to 12 inch (=30 cm), both of which run at 33⅓ rpm. Playing times are 15 and 25 minutes per side, respectively. This new material, with its almost amorphous structure, allowed much finer mechanical signal representation which made narrower grooves, lower speeds and, therefore, longer playing times possible. The amorphous structure also produced considerably less surface noise than shellac discs.

PVC/PVA co-polymer is chemically very stable. Apart from few very early discs, all are in good shape. The material is comparatively soft, however, and, therefore, vulnerable to mechanical damage, e.g. to scratches.

Deterioration by replay

With all mechanical formats the rate of deterioration in normal use is high. Most of the preserved mechanical records are, therefore, not in their original shape and quality. The quality and the correct adjustment of replay equipment is not only a constitutive factor for the replay of the signal.

Misalignments and inexperienced operation may severely damage, even destroy a mechanical carrier. Electrical shellac records from around 1930 onward and microgroove discs can be transferred by trained and skilled staff. Cylinders, early shellacs, and all instantaneous discs must be handed over to more experienced specialists. Contact IASA TC for advice.

MAGNETIC CARRIERS

Magnetic recording was invented in the 19th century. It was used on a small scale in parallel with cylinders and gramophones. In its present form, it was developed in the 1930s by AEG Telefunken and a practical system introduced in 1936. It became widely used within the German Radio. Because of World War II, however, its use was restricted to Germany. After the war, the technology came to the United States from where it spread worldwide. The use of this recording technology in the late 1940s and early 1950s was restricted to broadcasters and the recording industry. From around mid-1950s onward, however, home audio recorders were developed which operated at slower speeds. In the 1960s, several cassette formats were developed. Of the formats, the compact cassette swiftly dominated the market and is still in use today. In the early days of magnetic recording, wire recorders gained some popularity.

After a number of experiments, digital audio recording on magnetic tape was introduced in the 1980s. All of these early professional and semi-professional formats are now obsolete. In 1987, R-DAT, a digital recording cassette format, was developed which gained some popularity in semi-professional and professional circles. By 2006, however, it was also obsolete.

It should be noted that all audio-specific magnetic tape formats are now, in practice, dead. Audio recording, post production and storage have become part of the IT (computer) world with its non-audio-specific carriers and formats.

From 1956 onward, magnetic tape was also used for video recording. Several professional reel-to-reel formats were developed and used until the late 1970s. For home recording, early open reel formats came into use around 1970 and, around 1980, cassette home formats became widespread of which the VHS format still survives today. For small handheld camcorders ("handy cams") an 8mm cassette system became popular (Video8, VideoHi8) which was still in use in the early 2000s. Digital recording for professional use became common in the mid-1980s followed by digital home formats in the mid-1990s.

Video-specific magnetic tape formats are still in wide use, but a similar development to that which happened in the audio world is foreseeable in the mid term: video recording and storage will also become part of the IT world.

Beyond specific audio and video formats, magnetic media are the most prominent storage media of the IT world. Magnetic tape plays an important role as a computer backup medium and hard disk drives (HHD) have seen a tremendous spread both in professional and home applications. Magnetic disk technology is also increasingly spreading for portable recording and replay audio and video equipment as a competitor to classical tape formats. Both carrier types have become the backbone of professional digital audio and video archiving. While this publication concentrates on (traditional) audio and video tapes, the principles described are also more or less valid for magnetic computer media.

Recording principle

A magnetic tape is moved across a recording head. The head is an electro-magnet that produces a varying magnetic field according to the signal it receives from the recording device. This magnetic information is "frozen" within the magnetic layer of the tape at the moment it passes the recording head. The recorded signals can be retrieved by running the tape across a replay head which picks up the magnetic information and converts it back into an electric signal. With audio tape recorders, the head is stationary while the tape is moving. Analogue video, as well as digital audio and video signals, require a considerably higher band-width (= amount of data) which calls for higher recording speeds. This problem is generally solved by a rotating head which writes across the width of the tape at high speed, while the tape is moving forward at a slower speed.

It is important to understand that, in order to optimally retrieve the signal from a tape, an intimate tape to head contact is essential. This is one of the major reasons for keeping storage and handling areas clean.

Composition of magnetic tapes and stability of their components

Magnetic tape is composed of two layers: the base film and the magnetic layer. Additionally, many tapes have a matt back coating to improve winding properties and to reduce electrostatic charges.

Base film materials

In the sequence of the development of magnetic tapes, the following materials were used: cellulose acetate (AC), polyvinyl chloride (PVC), and polyester (polyethylene-terephtalate, PE or PET). AC has been used from the very beginnings in the mid-1930s until it faded out during the mid-1960s. AC deteriorates with time; it becomes brittle and shrinks. This deterioration process is highly dependent on the storage conditions the tape has been exposed to. High humidity levels and high temperature further deterioration. Therefore, the replay of many AC tapes presents difficulties. Generally, these tapes are grouped under endangered carriers and should be prioritised in digitisation programmes.

PVC tapes, produced mainly in Germany between 1944 and 1972, have not, as yet, shown to have systematic chemical deterioration. Generally, their replay does not constitute a problem. Due to their electrostatic behaviour, however, their winding properties are sub-optimal.

PE has gradually replaced AC and PVC tapes from the late 1950s onward. It has been used for all kind of magnetic tapes. PE is mechanically robust and chemically very stable.

Magnetic pigments

The first wide-spread magnetic pigment was γFe_2O_3 which was used for all open reel audio tape, compact cassettes of type IEC I, and the first video format (2 inch Quadruplex). γFe_2O_3 is brown rust and chemically stable. Because of the size of its elementary magnets, however, its capability for high data density is limited making it unsuitable for reduced recording speeds and, therefore, smaller tapes. In order to allow more practical handling of video tapes, chromium dioxide (CrO_2) was developed which permitted higher data densities leading to slower recording speeds and smaller tapes. Chromium dioxide and substitutes (cobalt-doped Fe_3O_4) have mainly been used for analogue video recordings and for compact cassettes type IEC II. It is considered to be chemically less stable than iron-oxide but no adverse observations in this regard have been made so far. The latest magnetic pigment is made from pure iron particles (MP, **M**etal **P**article). It is used for digital video formats, R-DAT, and compact cassettes type IEC IV. Because of its chemical nature it is potentially prone to oxidation. After problems with oxidation in early tapes, methods have been developed that have, so far, prevented any widespread problems with oxidation. However, in the mid- to long-term, MP tapes as well as ME (**M**etal **E**vaporated) tapes (tapes with a magnetic layer produced by evaporation under high vacuum) must be considered potentially endangered.

Pigment binders

Magnetic pigments are powders that need to be bonded together and onto the tape. In the sequence of tape development cellulose acetate, then PVC, and from the 1970s onward polyester urethane (PEU) was used. Old AC binders should be regarded as a risk, like AC tapes in general. PVC binder tapes, the bulk of the late 1950s and 1960s tapes, generally have no deterioration problems. Modern PEU binder tapes, however, frequently constitute a preservation problem. They are susceptible to hydrolysis (see chapter Water) whereby tapes become sticky. They often squeal during replay and shed sticky magnetic powder deposits on the audio and video heads. This clogs the heads and leads to a significant loss of high frequencies (audio) or a complete break down of the signal (video). Generally, such tapes can be reconditioned for replay. In severe cases, however, pigment binders totally break down which leads to a complete loss of the information carrying magnetic layer. Magnetic coatings also contain lubricants to minimise friction between the tape and the heads. Because of the higher head-to-tape speeds, video tapes contain more lubricants than audio tapes. The lubricants in some tapes have a tendency to be exuded. This again causes clogging of replay heads. Low storage temperatures (less than about 8°C) may aid further exudation and are, therefore, discouraged. Exuded lubricants can be removed by a mechanical cleaning process.

Stability of magnetic information

Contrary to a widespread fear, magnetic information does not vanish with time. Properly produced, stored and handled magnetic tapes do not lose their magnetic properties within a historically relevant timescale.

Deterioration by replay

In contrast to mechanical carriers, fairly modern and well preserved magnetic tape can be replayed several hundred times without any measurable loss of quality. However, a pre-condition is well-maintained replay equipment of the latest generation which handles the carriers gently. Old or poorly serviced machines may severely deteriorate if not destroy a tape during replay. Cleaning and de-magnetizing is an important routine measure to remove the danger of damage to tape surfaces or of magnetic deterioration of the tape.

OPTICAL CARRIERS

Optical carriers are the oldest audiovisual carriers. In the form of photographs, they have been in use for analogue image representation for almost 160 years. In the form of moving images, for over 100 years. For the storage of electronic audio and video signals, however, they are the youngest group of carriers. Although optical tape formats have been developed, they have not reached market acceptance. Therefore, optical audio and video carriers are restricted to disk[1] formats.

The ancestor of the present optical disks was the Laser Vision Disc which was developed for storing analogue video signals in the late 1970s. The basic technology, i.e. the composition of the disk, the use of a laser light beam for replay and format parameters of the disks but not the size, was taken over by the Compact Disc. This was standardized as a digital audio replication format in 1982 (Red Book standard). It was soon discovered that CDs would also be an ideal medium for the dissemination of general data, which gave birth to the "CD-ROM"[2] (= replicated data CD) in 1985 (Yellow Book standard).

By 1991, both recordable CDs (CD-Rs) and rewritable CDs (CD-RW, Orange Book standard) were developed. In order to increase the capacity of optical disks, mainly to make them suitable to store video films, the DVD (Digital Versatile or Video Disc) was introduced from 1995 onwards using the same recording principles as CDs. However, contrary to the single-sided CD with only one data layer, the DVD offers a maximum of two sides (double-sided) with two layers each (dual-layer). Further, by using smaller track dimensions, an increase in the storage capacity by a factor of 7 for each DVD layer was achieved. By 2005/06, to accommodate high definition video Programmes, the storage capacity was increased again by the use of lasers of shorter wavelength

1 Concerning spelling of disc vs. disk, this publication follows IASA orthography: Analogue **discs** use the classical spelling "disc", which is also well established in Libraries and Archives. Digital media are written **"disk"**, following the general practice of the IT world. This also includes optical **disks**. Please note, however, that Compact Discs and MiniDisc are trade names which must retain their spelling.

2 This publication follows the generally accepted terminology for the classification of optical disks. Originally, replicated disks used for general data were called CD-ROM. With the advent of recordable/rewritable CDs, this terminology becomes inconsistent. Recent publications on optical disks therefore divide them into – ROM (= replicated, **R**ead **O**nly **M**emory)), – R (=recordable), and RW or -RAM (= rewritable, **R**andom **A**ccess **M**emory. All three types may contain audio, video, or general data.

("blue laser"). The technology has led, however, to the introduction of two competing formats, the HD DVD and the Blu-ray Disc (BD). Both take another step towards smaller signal representation and thereby increased data density.

Finally, magneto-optical disks should be mentioned in this context. Originally used in the computer world for storing data, they have lost their earlier importance with the dramatic increase in storage capacity of hard disk drives (HDD) at ever lower prices. In the consumer world they have survived, however, in form of the (rewritable) MiniDisc.

Recording principle

Replicated CDs (CD-ROMs) consist of a transparent body of polycarbonate of 1.2mm thickness. On their upper surface this body carries an embossed (moulded) track of "pits" (holes) and "lands" (non-holes) of different lengths. The body is covered by a reflective layer, usually of aluminium, which, in turn, is covered by a protective lacquer which also carries any content/label information. A laser reads the information from underneath. It is focused on the track consisting of pits and lands. Due to a sophisticated relationship between the laser wavelength and the depth of the pits, a change in intensity of the reflected laser light is detected when pits change to lands and vice versa. Such changes represent digital ones while no change represents digital zeros.

DVDs have narrower tracks and shorter pit/land length and their laser uses a shorter wavelength. Additionally, they are only 0.6 mm thick. With single-sided DVDs, a blank second carbonate layer is bonded to the one carrying the information. With double sided disks, a second information carrying layer is attached. Additionally, with dual-layer DVDs it is possible to add to each data layer a second, semi-transparent layer, which makes two readable layers on each side, almost doubling the storage capacity.

In *recordable optical disks (dye disks, CD-Rs, DVD-Rs*), the information layer consists of a preformed groove in the upper surface of the polycarbonate body filled with an organic dye. A recording is made by a laser of much higher energy than the reading laser, which heats ("burns") the dye. By this means, a sequence or pattern of burned and non-burned spots are created which are recognized by the reading laser in the same way as the pits and lands of ROM-disks.

In *rewritable disks (CD-RWs, DVD-RWs or RAMs*) the information layer consists mainly of a metal alloy film which, by a sophisticated process of melting and controlled cooling, permits the creation of a pattern of amorphous and crystalline spots with different reflection properties, which can be read like CD-ROMs. This process is reversible.

Magneto-optical recording is based on phenomenon that magnetic orientation influences reflection of light (Kerr effect). The recording is achieved by heating the magnetic information layer with a laser beam beyond its Curie point, which allows magnetic (re-) orientation by applying very low magnetic fields. Replay works in a similar way as other optical disks. Actually a magnetic carrier, magneto-optical disks are generally discussed together with optical disks proper, as their architecture is very similar. In fact, replicated MiniDiscs are structurally identical with CD/DVD-ROMs.

Composition of carriers and stability of their components

The polycarbonate used for optical disk bodies is a transparent polymer. Early disks, especially LV disks, sometimes had problem with crazing, which made the polymer opaque and unreadable. It is hoped, however, that modern polycarbonate will be stable for several decades.

Aluminium, silver, silver alloys and gold are used as reflective layers. All, except gold, are prone to oxidation. The protective lacquer layer of CDs, therefore, plays an important role. It must be resistant against penetration of humidity, a function which often did not work properly with early CDs. Oxidised reflective layers, particularly aluminium, render optical disks unreadable.

With DVDs, the stability of the semi-transparent layer in dual layer disks is unknown. Also unknown is the stability of the bonding that keeps the two halves of a DVD together.

Another factor of great uncertainty is the stability of the dyes used in recordable CD/DVDs. There are three different dyes in use: Cyanine, phthalo-cyanine and azo. Cyanine and azo are considered less stable than phthalo-cyanine. All dyes are susceptible to light, specifically uv radiation. Exposing recordable CDs to daylight will render them unreadable within a few weeks. Generally, the life expectancy of dyes is often quoted to be between 5 and 100 years, information which, practically, is of little use. The stability of the semi-transparent layer of DVD-Rs is unknown. Finally, the stability of rewritable disks is also unknown and their potential life expectancy as compared to dye disks is unclear.

Recording quality as a constitutive factor of life expectancy of recordable optical disks

Recordable optical disks, mainly "dye disks" (CD-Rs, DVD-Rs) have become very popular media for audio, video, and data recording. As with many other digital carriers, their reliability depends on a sophisticated error correction system which allows the information to be fully reconstructed even if small parts of the medium have become unreadable by damage or deterioration because of ageing. The error correction capability is limited, however, and the quality of the recording becomes an important factor for life expectancy. A perfect, almost error free recording leaves sufficient error correction capability to compensate for handling and ageing effects and thereby enhances life expectancy. If, however, an optical disk starts its life with a high error rate, then there is little capacity left to correct further errors caused by misuse or aging. The effective life of such disks will be shorter. As a result, IASA has defined recommendations for maximum acceptable levels of errors for optical disks in order to maximize their life expectancy, whatever it may be.

The problem in burning optical disks is the interaction between blanks (unrecorded disks) and writers. There are no standards defined and the processes of automated adjustment do not always work sufficiently well. Tests have shown that randomly chosen blank/writer combinations produce 50% acceptable and 50% unfavourable results. Consequently, the reliable use of recordable optical disks requires extensive testing of writer/blank combinations, the checking of each single disk produced and further checking at regular intervals while the disk is in storage. As test equipment is expensive and testing labour-intensive, more reliable, and ultimately more cost effective, methods are used for professional data storage. (Further reading: IASA-TC 04, chapter 6.6)

Deterioration by replay

There is no (measurable) deterioration by replay with optical disks.

Part 2: Passive preservation – environmental factors, handling and storage

This part deals with common factors/issues across the various carriers:mechanical, magnetic, optical.

Humidity

Water is omnipresent in form of humidity of the air. It is the greatest natural enemy for all audiovisual carriers. It has direct chemical and indirect influences on the stability of carriers. Direct chemical influences are hydrolysis and oxidation of carrier components.

Hydrolysis is a chemical reaction between water, omnipresent in form of humidity in the air, and some polymers. The reaction changes the chemical and physical properties of the original polymer, often producing a by-product which acts as an auto-catalyst that enhances the destructive process.

In mechanical carriers this mainly affects the coating of lacquer discs which shrinks and becomes brittle with age. This may lead to the sudden crazing of the surface, rendering such discs unplayable. Hydrolysis also affects cellulose acetate base films, which become brittle with age. It is the process which also affects many PEU binders of modern magnetic tapes (see chapter "Pigment binder") with the well-known consequences.

Oxidation is another chemical reaction triggered by water. It is a potential threat to pure metal particle magnetic pigments used specifically for digital video recording (see chapter "Magnetic pigments"). It also affects the reflective layers of optical disks other than those of gold.

Direct contact with water is only dangerous for some kind of instantaneous discs, especially those made from gelatine. For most carriers it is not dangerous, as long as the contact is short and the carrier quickly and thoroughly dried. If water was contaminated in any way, the carriers will need to be carefully cleaned before drying.

The indirect influence of water relates to bio-degradation, specifically mould (fungus growth). This happens at relative humidities (RH) of 70% and higher. Fungus can grow on nearly all types of audiovisual carriers. It can grow on the surface of analogue discs and on magnetic tape surfaces rendering the carrier difficult, if not impossible, to replay. In severe cases, it virtually "eats" magnetic layers. It is also known to affect CDs, rendering them unplayable. Because of the potential for damaging carriers, both directly and indirectly, relative humidity must be kept low and any direct contact with water must be kept as short as possible.

It must also be noted that relative humidity and temperature are interrelated (for more details see under chapter "Temperature").

Temperature

Temperature influences audiovisual carriers in various ways:

Physically it causes dimensional changes. Generally, carriers expand with rising and shrink with falling temperatures. There is one anomaly, however. Polyester tape base films are pre-tensilised. Their thermal expansion is significantly bigger in the dimension of thickness than of length. Thus, polyester tapes swell with rising temperatures, thereby increasing the tension within the tape pack. Acetate and PVC tapes react in the opposite and more expected way – their winds get looser with rising temperatures and tighter with falling temperatures. Dimensional changes are particularly dangerous for lacquer discs, as they can trigger the crazing of the lacquer coating. This is because of the different thermal expansion of the metal or glass substrate and the brittle lacquer coating. Another physical effect of temperature is its influence on print-through in magnetic tapes which increases with rising temperatures.

The chemical influence of temperature differs for various carriers. Different materials are affected in different ways at different temperatures. It can be stated, however, that temperatures between approximately 8°C and 35°C have no immediate direct deteriorating influence on any known audiovisual carrier.

However, a change in temperature alters the speed of chemical processes and, as a result, ageing or deterioration. By a rough rule of thumb, the speed of a chemical process is doubled by an increase of 10°C, or, alternatively, the speed of ageing is slowed by 50% by lowering temperature by 10°C.

Consequently, in order to prolong the life of audiovisual carriers by slowing chemical deterioration and, thereby, ageing, it is prudent to keep humidity, and temperatures low. As sudden climatic changes between handling and storage areas must be avoided, two standards for storing audiovisual carriers are recommended:

Preservation storage:	25-30% RH ± 5%,	8 – 10°C ± 1°C.
Access storage:	40% RH ± 5%,	~ 20°C ± 3°C.

It must be understood that all values between 20 and 65% RH, and 8° and 35°C have no immediate devastating influence on any audiovisual carrier. The choice of specific values is always a compromise between accessibility, comfort for operators and cost. On the other hand, it must be noted that even the lowest affordable values do not prevent, but only slow deterioration. Archives should choose those parameters which they can afford to keep 24 hours a day all year round.

In closing the chapters on "Humidity" and "Temperature" it is important to note that the parameters are interrelated. The temperature determines the maximum amount of water that can be held by the air in gaseous form (vapour). Higher temperatures mean that the air can hold more water vapour, while at lower temperatures the air can hold lower amounts of vapour. If a given room is cooled without simultaneously dehumidifying the air, the relative humidity rises until an RH of 100% is reached. This temperature is called the dew point, at which excess vapour condenses in the form of water on the coldest surfaces. Any air conditioning must, therefore, control both parameters simultaneously. It must be noted that most conventional air conditioning equipment will not dehumidify sufficiently to keep the RH stable as the temperature drops. The plant will inadvertently lead to a rise in relative humidity and, therefore, to an increased threat to carriers, counter-acting any benefits of the lowered temperature.

Mechanical deformation

Mechanical deformation is a major threat, particularly for mechanical carriers. Fragile carriers (cylinders, shellac discs) can break and all are prone to surface damages, which will cause audible artefacts (clicks). Similarly, optical disks must be kept free of mechanical damage and scratches. Scratches on the read-out surface will obstruct the laser beam, while a damaged protective layer will endanger the chemical integrity of the reflective layer. Mechanical integrity is also a commonly underrated factor in magnetic tape preservation. In order to minimise stress, specifically with brittle AC tapes and all kind of thin tapes (long-, double- and triple-play), tape handling by replay equipment must be optimised by using the latest generation of equipment. Most importantly, all open reel and cassette tape must be stored with absolutely flat wound packs only, as any steps in the wind will cause curled tape edges which result in a variety of replay problems. Flat winds can best be achieved by winding the tape after use over its entire length in one go. Machines failing to achieve such winds must be serviced or exchanged. With cassette tapes, the loading and unloading procedure constitutes a significant stress to the tape resulting in measurable drops-outs after several tens of such actions. Consequently, cassettes must only be loaded and unloaded at the unrecorded portions at the beginning or at the end of tape. Therefore, when recording a programme on a cassette, sufficient room should be left blank as a loading area, preferably at both ends.

Dust, foreign matter, (air) pollution

Dust and foreign matter have a variety of effects on audiovisual carriers. With mechanical carriers they cause deviations of the stylus, resulting in audible artefact (clicks). With magnetic tape, dust and foreign matter clogs the replay head and prevents intimate tape-to-head contact which, in audio, causes high frequency loss and, in video, the swift breakdown of the signal. With optical disks, the reading laser is obstructed which may lead to uncorrectable errors and, eventually, muting.

Dust and foreign matter are of different origin. A major source is mineral dust, particularly in southern, arid countries. Another prominent form of dust in urban environments is textile particles. Carpeted floors, as widely used in offices in the 1970s, are, therefore, absolutely forbidden throughout the entire audiovisual archive. Beyond those sources of dust, other typical annoying materials are fingerprints – which additionally act as glue for dust – and consumables. With magnetic tape, there are also problem materials from the tape itself. Dry abrasion (mainly with old tapes) and smear from hydrolysed tapes constitute a major self obstruction in the replay of deteriorated tapes.

Air pollution, specifically industrial gaseous waste, can also affect audiovisual carriers in many ways. It may be assumed that environments regulated by modern standards in the interest of human health will not be immediately harmful to audiovisual carriers. Should archives, however, be in the vicinity of industrial areas, it may be wise to consider appropriate air filtering. The exposure of materials to fumes caused by refurbishing work like painting, gluing, etc. must be critically watched. Appropriate measures have to be taken to avoid any (prolonged) exposure to such vapours.

Light, uv radiation, x-rays

Light and uv radiation have several deteriorating effects on audiovisual carriers. Many polymers, e.g. PVC, deteriorate under prolonged or permanent exposure to light. Extremely dangerous is the influence of light on the life of recordable CDs and DVDs ("dye disks"). Tests have shown that permanent exposure of such disks to daylight – and specifically to direct sunlight – render them unreadable with weeks. It is wise, therefore, to avoid any unnecessary exposure of all types of audio and video carriers to light. In addition, carriers should be well screened from sunlight as, in additional to the deteriorating effect of light, the temperatures generated may be destructive. X-rays, as emitted from airport equipment, have no influence on audio and video carriers, unlike undeveloped films. Even the extremely high doses used to decontaminate objects contaminated by bacteria like anthrax spores, do not harm the recorded signals. It is not known, however, whether, and to what extent, such treatment may influence the life expectancy of treated materials.

Magnetic stray fields

Magnetic stray fields are the natural enemy of magnetic recordings. The susceptibility of magnetically recorded signals to deterioration up to erasure depends on the coercivity of the magnetic material, which is the resistance of a given magnetic material to being magnetically re-orientated, and the kind of signal representation on the tape.

For medium coercivity magnetic tape as is typically used for analogue audio recordings (coercivity around 400 Oe (Oersted)) the maximum permissible field strengths have been determined to be:

5 Oe (= 400 A/m) AC
25 Oe (= 2000 A/m) DC

Chromium and metal tapes have higher coercivities.

The most susceptible signal representation is analogue (linear) audio recording which also occurs on the audio tracks of video tapes. FM audio, all video, and all digital recordings are more resistant to magnetic influences.

The most dangerous sources of magnetic stray fields typically found in audiovisual archives are dynamic microphones, dynamic head phones, loudspeakers and moving coil instruments (level meters). As the field strength falls exponentially with distance, even the strongest fields produced by these gadgets are, at a distance of 15 cm to recorded tapes, well below the above mentioned thresholds.

Generally, there a few other dangerous sources of magnetic stray fields. Magnetic board stickers must be avoided absolutely as inadvertent direct contact with magnetic tape will be harmful. Thought should also be given to the lightning conductor system of a building. Magnetic carriers have to be stored at the greatest possible distance to conductors. Also, big transformers and electric motors may influence magnetic carriers.

Storage and shelving

The location of storage areas within a given building should be given high consideration. Ideally it should be in the centre of a building, slightly elevated from the ground floor. Such a location would allow effective and autonomous control over all environmental factors, temperature, humidity and water, dust and pollution, light, as well as magnetic stray fields to be achieved. Any location at the fringe of a building would make such control more difficult, and possibly less effective. Any location lower than ground level makes air conditioning more expensive. Vaults should be fireproof, thermally insulated and also protected against water influx, which may happen for a number of reasons.

Today, metal (steel) shelves are generally used. There is no risk in using them for storage of magnetic carriers, as long as they are not magnetized themselves and as long as there is no risk of them becoming part of the lightning conductor system in the event of a strike. Wooden stacks, preferred in the 1950s and 1960s, are now discouraged as chemical treatment components may interact with audiovisual carriers.

All carriers – discs, tapes and cassettes – should be stored upright. Only soft, instantaneous discs, like gelatine or decelith discs, should be stored horizontally in small piles, not more than 10 discs high.

Storage areas should be air conditioned to parameters discussed above. Ideally, their air should be filtered. A slight overpressure in vaults will prevent the intrusion of dust. The floor should be of sealed concrete or other non abrasive materials such as tiles – dark coloured to make dirt visible.

General risks

Fire

Fire prevention and extinguishing must be given utmost importance. Beyond the safeguarding of invaluable material, it must be understood that burning audiovisual carriers produce highly toxic fumes which are of considerable risk to environment and health In addition to irreplaceable losses of holdings, complicated and expensive decontamination of premises may be the result of such incidents.

Ideally, the entire building should be separated into appropriate fire zones and equipped with a fire detection system. The storage area should be fireproof and equipped with an automated fire extinguishing plant. Today, halon replacement gases are generally used for traditional materials as well as server rooms of digital archives. So called “dry fog” systems, spraying very finely dispersed water into the vault, are gaining popularity with traditional materials as the cooling effect is of great support for the protection of carriers while water damage is minimal.

Hand held fire extinguishers should contain CO_2. Water, foam, and particularly powder, the most popular agent used in office-type extinguishers, must not be used.

Water

Apart from keeping humidity low (see above), special attention should be given to the prevention of water influx, which may be from several possible sources. Storage areas should, therefore, be safeguarded against water influx from all sides. This is easier to achieve if the stores are located in an elevated position above the ground floor. A waterproof ceiling will prevent any influx of water caused by plumbing leakages and water from fire extinguishing in upper floors. There should be no connection to the sewerage system, which, in case of floods, would be a path for influx. If an underground location cannot be avoided, careful consideration must be given to the prevention of influxes as a result of inundations. The installation of automated pumps may be advisable. In any case, materials should be stored at some distance above the floor to safeguard them for some time to allow preventive actions to become effective in the case of influx.

Summary of carrier preservation

It can be said with some justification, that all audio and carriers are more endangered than conventional text documents. This applies whether the danger be from the chemical instability of carriers, the inherent vulnerability to external hazards or from the fact that mere replay deteriorates some types of carriers. Specific structural measures for access to and preservation of these carriers have, therefore, to be installed. These will go well beyond basic preventive measures as established for most conventional text materials.

Even the tight adherence to all the above standards and recommended practices is no guarantee against accidental loss of documents. Even well maintained replay equipment may unexpectedly fail and destroy a carrier. Digital documents may disappear without any pre-warning at any time. Consequently, the most important principle of all is that at least two copies of each document must be available at any time. Vulnerable and unstable original carriers must be copied to sturdy and reliable archival formats. At least two copies should be made and held in different places for additional protection of the information in the case of disaster. For access, appropriate work copies should also be made. Unlike text documents in libraries and archives, master copies of audio and video carriers must never handled by patrons but by trained staff only.

Part 3: Maintenance of equipment, obsolescence of formats and equipment

Maintenance of equipment

All audio and video documents are machine readable formats and, as discussed above, equipment has a major influence on the integrity and life expectancy of the carriers. As a matter of principle, only the most advanced equipment of the latest generation that provides the gentlest of handling should be used to replay carriers. This equipment must fully comply with historical format parameters. In addition to gentle handling, modern equipment will also introduce the least possible replay distortion, thus making almost 100 % of the signal quality retained on carriers accessible (cf. IASA-TC 03 and IASA-TC 04, chapter 5).

Unsuitable or un-serviced equipment may damage, if not destroy carriers. Replay equipment should, therefore, be initially set up and aligned by experts, preferably by qualified staff members. If commercial services are engaged, their professional standards, reliability and honesty should be carefully examined. Cleaning (including degaussing – de-magnetising – of replay equipment for magnetic formats) and routine checks must be performed regularly. The frequency of checks etc. depends upon the duration of use of the machine and the debris etc produced by replay. Measurement of performance and realignment at regular intervals, e.g. 50 -100 hours of use for analogue audio tape magnetic recorders, is indispensable.

For these routine tasks, reliable and skilled personnel, not necessarily having a technical education in a narrower sense, can be employed. These operators must also be instructed to notice (unexpected) irregularities and to report them for investigation by more expert people. Difficult alignments may need outsourcing; however, quality control must be performed by the archive. A minimum set of test equipment must, therefore, be available in every audiovisual collection. It is also essential to keep log books for every piece of equipment, recording all routine checks, services, alignments and repairs.

Obsolescence of formats and equipment

As all audio and video recordings are machine readable documents, even documents in perfect condition would be useless without replay machines. The availability of equipment and spare parts, however, depends on mass production which is suspended when formats become obsolescent. The pace of technology, particularly of digital technology, over the past two decades has led to ever shorter cycles of innovation. Additionally, new recording formats and systems have become increasingly sophisticated. While it is possible to construct a new cylinder replay machine which greatly exceeds the performance of historical equipment, it will require considerable effort to keep analogue audio tape recorders in good working conditions once the official supply of spare parts has ceased. It will be totally impossible to keep sophisticated digital video recorders in playing condition after support from the manufacturers has come to an end.

Format obsolescence and availability of equipment Audio			
format	obsolete now	obsolete soon	equipment
cylinders	x		specialist only
coarse groove discs	x		specialist only
micro groove discs (vinyls)	x		fading out
quarter inch tape	x		fading out
micro cassettes	x		fading out
compact cassette		?	?
DASH+ProDigi	x		specialist only
R-DAT	x		fading out
MiniDisc		?	?

Format obsolescence and availability of equipment Video professional			
format	obsolete now	obsolete soon	equipment
2” quadruplex	x		specialist only
1”	x		specialist only
Umatic	x		fading out
M II	x		specialist only
Betacam SP	x		?
D 1	x		fading out
D 2	x		fading out
D 3	x		fading out
D 5	x		fading out
DigiBeta		?	?
IMX		?	?
DVCPRO		?	?

Format obsolescence and availability of equipment Video home			
format	obsolete now	obsolete soon	equipment
Laser vision disc	x		specialist only
VCR	x		specialist only
Video 2000	x		specialist only
Betamax	x		specialist only
VHS		?	?
S-VHS		?	?
Video8	x		?
Video Hi8	x		?
Digital 8		?	?
DV		?	?

The tables above reflect the experiences that audiovisual archivists face today (winter 2007/08). For audio this means that new replay machines for quarter inch open reel and R-DAT have already become hardly available and spare part supply for professional equipment is fading out. Obsolescence of formats and equipment is accompanied by rapid obsolescence of ancillary objects, such as calibration tapes, leader and splicing tapes, empty reels and hubs and, most notably, professional servicing capabilities. The immediate threat for video lies in the fact that most earlier digital formats are already obsolete, and even VHS, the world's most widespread video format, may disappear very soon with the increasing success of DVD

Audio has already left all its specific formats – both analogue and digital – apart from CD-Audio behind. Recording, processing and safeguarding of audio contents has become a domain within the computer world. The Microsoft Wave-format has become a de-facto standard. Video has not yet reached this state but the same development is foreseeable. Within a few years all video specific recording systems will become outdated to be replaced by the handling of video signals as true file formats by computers. This means that all video formats currently in use will be obsolete in the near future.

In view of the enormous quantity of specific audio and video carriers in our archives, audiovisual archivists are advised to adhere to the following safety strategy measure in order to deal with this situation with some hope of success:

– calculate the need for additional **modern** equipment and spare parts based on the size of the collection.
– look out for recording studios and broadcast stations changing over to digital production and buy any good quality redundant machines that are available.
– obtain supplies of calibration, leader and splicing tapes.
– buy a stock of analogue test equipment.
– check the second hand market (e-bay) regularly.
– collect service manuals for old equipment.
– train young technicians in the maintenance of obsolete and obsolescent equipment.
– hire retired studio, radio and television technicians to assist in keeping service skills alive.

At present, following the latest development in audio and video technology, audiovisual archivists consider obsolescence of formats and equipment to be **even more dangerous** than carrier degradation.

Summary

Around 1990, sound archivists began to understand that further pursuance of the classical paradigm of preservation, namely to preserve the original object placed in their care, would be in vain, as all audiovisual carriers are prone to decay and all audiovisual record/replay systems are threatened by obsolescence. Preservation efforts must concentrate on the content which can only be preserved by migration from one system to the next. As every generation of analogue copying would further deteriorate the signal, this chain of migrations can only successfully be achieved in the digital domain which permits an unlimited number of subsequent copies. Therefore, analogue content has to be digitised first.

This new preservation paradigm was initially not without dispute. By the mid-1990s, however, it was generally accepted and systematically introduced by European broadcast sound archives. Now, national and research archives are following. This principle has also become the model for long term video preservation.

Select bibliography

This bibliography does not intend to give a full overview of the literature available on preservation of audiovisual carriers. It concentrates on recent publications of a general character, which themselves are pointers to further and more specialist literature. Most of them are also available on the internet.

AES-Standards, available from http://www.aes.org/publications/standards/list.cfm:

AES22-1997 (2003): AES recommended practice for audio preservation and restoration – Storage and handling – Storage of polyester-base magnetic tape

AES28-1997 (2003): AES standard for audio preservation and restoration – Method for estimating life expectancy of compact discs (CD-ROM), based on effects of temperature and relative humidity (includes Amendment 1-2001)

AES35-2000: AES standard for audio preservation and restoration – Method for estimating life expectancy of magneto-optical (M-O) disks, based on effects of temperature and relative humidity.

AES38-2000: AES standard for audio preservation and restoration – Life expectancy of information stored in recordable compact disc systems – Method for estimating, based on effects of temperature and relative humidity.

AES49-2005: AES standard for audio preservation and restoration – Magnetic tape – Care and handling practices for extended usage

AES-11id-2006: AES Information document for Preservation of audio recordings – Extended term storage environment for multiple media archives

Boston, George (ed): Safeguarding the Documentary Heritage. A guide to Standards, Recommended Practices and Reference Literature Related to the Preservation of Documents of all kinds. UNESCO, Paris 1998
web version: http://www.unesco.org/webworld/mdm/administ/en/guide/guidetoc.htm extended CD-ROM version UNESCO, Paris 2000 (available from j.springer@unesco.org)

Bradley, Kevin: Risks Associated with the Use of Recordable CDs and DVDs as Reliable Storage Media in Archival Collections – Strategies and Alternatives. UNESCO, Paris 2006
web version: http://www.unesco.org/webworld/risk

Byers, Fred R.: Care and Handling of CDs and DVDs – A guide for Librarians and Archivists. NIST Special Publication 500-252. National Institute of Standards and Technology, Washington DC, 2003
web version: http://www.itl.nist.gov/div895/carefordisc/
Warning: This otherwise very useful publication fails to discuss the quality of the recording as a determining factor of life expectancy

IASA Task Force on Selection, Marcella Breen et al.: Selection criteria of analogue and digital audio contents for transfer to data formats for preservation purposes. International Association of Sound and Audiovisual Archives (IASA) 2004.
web version http://www.iasa-web.org/taskforce.pdf

IASA Technical Committee: The Safeguarding of the Audio Heritage: Ethics, Principles and Preservation Strategy, edited by Dietrich Schüller. (= IASA Technical Committee – Standards, Recommended Practices and Strategies, IASA TC-03), Version 3, 2005
web versions:
http://www.iasa-web.org/IASA_TC03/TC03_English.pdf
http://www.iasa-web.org/IASA_TC03/TC03_German.pdf
http://www.iasa-web.org/IASA_TC03/TC03_French.pdf
http://www.iasa-web.org/IASA_TC03/TC03_Swedish.pdf
Spanish and Russian version upcoming

IASA Technical Committee: Guidelines on the Production and Preservation of Digital Audio Objects, edited by Kevin Bradley. (= IASA Technical Committee – Standards, Recommended Practices and Strategies, IASA TC-04), 2004
Also available in Spanish: Lineamentos para la producción de objetos de audio digitales. Radio Educación, Mexico, 2006

JTS – Joint Technical Symposia, Proceedings
1983 Stockholm
1987 Berlin
1990 Ottawa
1995 London
2000 Paris
2004 Toronto
2007 Toronto, forthcoming

Contact the IASA TC for information about obtaining copies
Kunej, Drago, Instability and Vulnerability of CD-R Carriers to Sunlight. In: Proceedings of the AES 20th International Conference Archiving Restoration, and New Methods of Archiving, Budapest, 5-7 October 2001, AES New York 2001, 18-25
Library of Congress, Cylinder, Disc and Tape Care in a Nutshell
http://lcweb.loc.gov/preserv/care/record.html
Memory of the World, Sub-Committee on Technology: Preserving our Documentary heritage. UNESCO, Paris 2005.
http://portal.unesco.org/ci/en/ev.php-URL_ID=19440&URL_DO=DO_TOPIC&URL_SECTION=201.html
also available in French, Spanish and Arabic
Plathe, Axel, and Dietrich Schüller, Coordinators, Safeguarding Documentary Heritage. A Virtual Exhibition
http://www.unesco.org/webworld/virtual_exhibit/safeguarding/expo00.html
St-Laurent, Gilles, The care and handling of recorded sound materials (1996)
http://palimpsest.stanford.edu/byauth/st-laurent/care.html
Schüller, Dietrich, Preservation of Audio and Video Materials in Tropical Countries. In:
IASA Journal 7/1996, 35-45
web version: http://www.unesco.org/webworld/audiovis/reader/7_5.htm*
Schüller, Dietrich, Preserving the Facts for the Future: Principles and Practices for the Transfer of Analog Audio Documents into the Digital Domain. In: Journal of the Audio Engineering Society (JAES) 7-8/49, 2001, 618-621

Deutsch

Schüller, Dietrich, Behandlung, Lagerung und Konservierung von Audio- und Videoträgern. In: Das audiovisuelle Archiv 31/32, 1992 (1993), 21-62 (CD-R, DVD fehlen, sonst im Wesentlichen noch gültig)

----

* This web version does not contain a bibliography. For the complete paper, consult printed version.