Causes and Measurement of Videotape Decay

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June 8, 2009

Videotape is at best a medium term storage format"
-National Television Preservation Study
Library of Congress, April 1997

Introduction

In the era of internet television, videotape libraries are becoming an increasingly valuable source of revenue. Unfortunately, scientific research has shown that videotape deteriorates over time. For this reason, content owners must be careful to identify tapes that are reaching a critical level of decay, and take steps to preserve them, so that the opportunity to monetize content in the future is not lost. This White Paper reviews the scientific literature on tape deterioration, identifies which types of tape are most at risk, and offers recommendations for how best to safeguard these important assets.

Background

Since the videotape recorder was first marketed commercially in the 1950s, there have been at least 11 different kinds of professional video recording technologies. Each of these so-called "legacy" formats had its own uniquely engineered type of videotape. A partial list of these formats includes 2 inch Quadruplex (Quad), ¾ Inch U-matic, 1 inch type C, Betacam, Betacam SP, M2, Digital Betacam, D1, D2, and D3.

No matter what the format, all of these types of tape shared the same basic chemical and electromagnetic characteristics. Videotape consists of millions of microscopic metal particles, called "particulate," or "oxide," which are suspended in a long, thin strip of flexible polyurethane known as "binder." Binder is delicate, so it is applied as a coating to a more durable layer of flexible polyester backing called "substrate." When the coated substrate passes over the electromagnetic recording head of a videotape recorder, the metal particulate is encoded with video and audio signals.

In the early years of video recording technology, little thought was given to the longevity of videotape. Manufacturers such as Sony and Ampex were focused primarily on hardware issues. To the extent that they considered tape, it was to create formulations with improved performance characteristics such as signal to noise ratio and dynamic range.

This attitude changed in the late 1970s, when it became apparent to the broadcast networks that their early Quad videotapes were deteriorating. Quad tapes recorded in the 50s and 60s had lost significant color saturation, hue, and audio volume. Further, these tapes were shedding their oxide coating. Some Quad tapes were already damaged beyond repair. As a result, the networks embarked on large scale preservation campaigns that transferred thousands of hours of endangered programs to a new format, 1 inch type C.

The deterioration of Quad format tapes also precipitated the first scientific studies into the question of tape longevity. What these studies found was that videotape is a surprisingly fragile medium, with inherent chemical and electromagnetic instabilities, which makes it inappropriate for long term archiving.

The two main reasons for this are scientific phenomena known as binder hydrolysis and magnetic remanence decay.

Binder Hydrolysis

Videotape binder is a complex mixture of polyurethane, lubricants, and cleaning agents. Its purpose is to bond metal particulate to a tape's underlying substrate. Unfortunately, research has shown that polyurethane binder loses its adhesive qualities over time. The primary reason for this is a molecular phenomenon known as binder hydrolysis.

Binder hydrolysis occurs when videotape binder absorbs water molecules from the air. As the binder absorbs moisture, its underlying molecular structure is progressively weakened, and it begins to separate from the substrate. This effect is known as "binder shed." When binder shed occurs, the encoded magnetic particulate embedded in the binder is irretrievably lost, causing dropouts, color loss, and a decrease in signal to noise. Binder shed manifests itself as a fine powder and/or a sticky residue.

Several studies have investigated hydrolysis and binder shed. The Jet Propulsion Laboratory at the California Institute of Technology (CIT) conducted the earliest in 1982. The authors found that binder hydrolysis varied as a function of temperature and relative humidity (RH), with humidity levels being more important than temperature. They developed a set of equations that showed binder shed due to hydrolysis would eventually affect all polyurethane-based binder, although reducing relative humidity to very low levels could slow this effect. For this reason, the CIT study recommended that tape be stored below 65 degrees Fahrenheit and 40% RH. (Cudihy and Brown, The Kinetics of Humid Aging of Videotape, California Institute of Technology, May 1982).

Subsequently, from 1984-1987, the Polymer Science Division of the National Bureau of Standards (NBS) conducted a long term study of the effects of hydrolysis. This research used accelerated aging techniques to determine how long it would take hydrolysis to reach unacceptable levels under various conditions of heat and humidity. The results suggested that the CIT storage standard (65F, 40% RH) would delay the onset of hydrolysis by approximately 20 years. The NBS authors recommended an even more stringent standard of 60F and 25% RH, which they projected would delay hydrolysis by approximately 30 years.

Eventually, the CIT and NBS findings were used to develop SMPTE's guidelines for tape storage, which specify that tapes held for more than 10 years should be stored at no more than 62F and 30% RH. (SMPTE Engineering Guideline EG44-2005. Care, Storage, Operation, Handling and Shipping of Magnetic Recording Tape for Television).

In practice, most tape libraries never adopted the SMPTE tape storage standard. This was because of the high cost of cooling and dehumidifying such large spaces, and the low priority that was given to tape archives at the time. Even today, a typical "cold storage" facility maintains conditions somewhere between office air conditioning and the CIT standard, which would suggest that most tapes currently in storage are already at risk of hydrolysis.

Table One shows the average current age of the various legacy formats, along with an estimate of their current risk of hydrolysis, assuming storage under cool, low humidity conditions. Formats with an average age over 20 years are rated "High Risk." Formats with an average age over 15 years are rated "Medium Risk." Formats under 15 years old are rated "Low Risk."

Table One: Average Age of Tape Formats and Risk of Hydrolysis

Format	Years Manufactured	Average Age	Risk of Hydrolysis
Quad	1954-1978	43	High
¾" U-Matic	1970-1990	30	High
1" Type C	1978-1991	25	High
Betacam	1982-1987	25	High
M2	1985-1987	23	High
Betacam SP	1987-1993	19	Medium
D1	1986-1995	18	Medium
D2	1988-1995	17	Medium
D3	1988-1995	17	Medium
Digital Betacam	1995-Present	7	Low

As can be seen from this table, 90 % of legacy formats are already in either the High Risk or Medium Risk categories for damage due to the onset of hydrolysis.

Magnetic Remenance Decay

A second source of videotape instability is magnetic remenance decay.

Over the years, manufacturers have experimented with many different types of metal particulate, including iron oxide, co-modified iron oxide, chromium dioxide, metal particle, and modified metal particle. The primary purpose of this experimentation was to increase the signal performance characteristics of the tape.

A series of studies in the early 90s examined the molecular stability of various kinds of metal particulate. These studies found that the ability of particulate to hold a magnetic charge decays over time. This signal deterioration is called "magnetic remanence decay." It results in a reduction in the clarity and volume of sound, and a reduction in picture hue and color saturation. This effect can be measured as a loss of decibels (dB), with losses of 2-3 dB (20%-30%) considered to be serious signal degradation.

The Advanced Development Corporation (ADC) conducted the first scientific study of remenance decay in 1990. It subjected a wide range of tapes to accelerated environmental aging tests. It found that different formulations of particulate experienced different rates of remenance decay. Ironically, the higher-performance particulates, such as chromium dioxide and metal particle, decayed at faster rates than the lower-performance particulates, such as iron oxide and co-modified iron oxide.

The ADC study projected that remenance decay in the high-performance particulates would cause a signal loss of 1-2dB (10-20%) after approximately 15 years, while the low-performance particulates were nearly stable (Speliotis, Dennis. "Corrosion of Particulate and Thin Film Media." Advanced Development Corp., January 1990).

The Sony Corporation conducted a second study in 1992. It focused primarily on high-performance particulates, and projected that these would experience approximately 2dB (20%) of signal loss after approximately 24 years (Ozaki, Y. "Estimating the Archival Life of Metal Particle Tape." IEEE Transactions on Magnetics, Sept 1992).

A third study on remenance decay was conducted by the Fuji Corporation in 2000. This study analyzed actual high performance particulates that had been stored under laboratory conditions for 14 years. It found that remanent magnetization in these tapes had declined by approximately 12% from their initial state, closely confirming the earlier projections work of ADC and Sony (O Kanagawa. "The Storage Stability of Metal Particle Tape," May, 2000).

In 1994, Sony introduced a new formulation of particulate, named “Reformulated Metal Particle,” which had a much improved rate of remenance decay. This particulate arrived too late for most videotape formats, but was subsequently adopted for data storage media, and is still in use today.

Table 2 shows the various legacy formats, with their respective particulate types, stability ratings, and risk of remenance decay in excess of 2dB. Formats over 20 years old that were made with unstable particulate are rated “High Risk.” Formats under 20 years old that were made with unstable particulate are rated “Medium Risk.” Formats of any age made with stable particulate are rated “Low Risk.”

Table 2: Risk of Remenance Decay

Format	Particulate Type	Avg. Age	Stability	Risk
Betacam	Chromium Dioxide	25	Unstable	High
M2	Metal Particle	23	Unstable	High
Betacam SP	Metal Particle	19	Unstable	Medium
D2	Metal Particle	18	Unstable	Medium
D3	Metal Particle	18	Unstable	Medium
2” Quad	Iron Oxide	43	Stable	Low
¾” U-matic	Iron Oxide	30	Stable	Low
1” Type C	Co-Modified Iron Oxide	25	Stable	Low
D1	Co-Modified Iron Oxide	19	Stable	Low
Digital Betacam	Reformulated Metal Particle	7	Stable	Low

As can be seen from this table, 50% of legacy tape formats are currently at Medium or High Risk of signal deterioration due to remenance decay.

Assessing Overall Risk

Because the life expectancy of videotape is a complex function of its age, chemical composition, electromagnetic properties, and storage environment, predicting the overall likelihood of decay of a specific tape is difficult. However, the scientific research into binder hydrolysis and remenance decay, taken together, makes it possible to identify which tape formats are currently most threatened. These are set out in the “Overall Risk” column of Table 3.

Table 3: Tape Format Overall Risk Ratings

Format	Hydrolysis Risk	Remenance Risk	Overall Risk
Betacam	High	High	Very High
M2	High	High	Very High
2” Quad	High	Low	High
¾” U-matic	High	Low	High
1” Type C	High	Low	High
Betacam SP	Medium	Medium	Medium
D1	Medium	Low	Medium
D2	Medium	Medium	Medium
D3	Medium	Medium	Medium
Digital Betacam	Low	Low	Low

As can be seen from this table, half of the 10 legacy formats are in the “Very High Risk” or “High Risk” categories. These formats are: Betacam, M2, 2” Quad, ¾” U-matic, and 1” Type C. Content stored on these formats requires immediate attention to prevent serious damage from hydrolysis, remenance decay, or both. (See “Preservation Options” below.) An additional 40% of legacy formats are currently in the overall “Medium Risk” category. These tapes should be monitored closely for early signs of deterioration. Only one format, Digital Betacam, is in the Low Risk category, requiring no immediate action.

It is important to note that these estimates assume storage in a cool, low humidity, environment. Tapes that have been stored under suboptimal or unknown conditions should be evaluated immediately, regardless of risk rating, due to the possibility of accelerated deterioration.

Preservation Options

Tapes that are rated Very High Risk or High Risk require immediate intervention to prevent potentially irreversible damage. There are two types of preservation options: Migration and Digitization.

Migration

Migration was the preservation technique used by the broadcast networks in the late 70s to address the problem of 2” Quad tape deterioration. Each network set up a dedicated battery of 2” Quad and 1” Type C machines, and used them to “migrate” the endangered materials from one format to the other. This created a new generation of 1” Type C transfer masters. Although this was considered a good solution at the time, it had several drawbacks.

First, because the 2” Quad source tapes and the 1” Type C transfer masters were both analog formats, the copying process inevitably introduced a new level of noise into the re-recorded signal. In effect, the very process of preserving the content contributed to its continued deterioration.

Second, migration did not solve the problem of tape decay; it merely pushed it into the future. Today, the very 1” tapes that were used as transfer masters in the 70s have themselves become endangered.

Finally, the re-recording process was expensive and time consuming. It required an investment in multiple tape machines and operators, as well as the dedication of space, infrastructure, and engineering support. The process could only be conducted in real time.

Today, videotape migration is still a preservation option. A new set of transfer masters can be made using one of the new, highly stable formats, and stored under conditions meeting SMPTE standards. However, many of the same drawbacks that existed in the 70s would still apply today.

Digitization

Fortunately, digitization, a new method for addressing this problem, is now available. This involves using digital processing to encode and store endangered video content as digital data files. This approach has several advantages over migration.

First, the content can be encoded and stored purely in the digital domain, at a very high quality level, using highly stable data storage media.

Second, if the content has already been damaged, it may be possible to reverse or mask the symptoms through the use of digital restoration techniques.

Third, once the content has been preserved digitally, it can be much more easily searched, retrieved, and distributed. This in turn greatly enhances opportunities for monetization.

Summary and Conclusions

This paper has reviewed the principal scientific research on videotape decay. These studies identified two main determinates of tape life: binder hydrolysis and magnetic remanence decay. Taking both kinds of deterioration into account, legacy formats were divided into four overall risk categories: Very High Risk, High Risk, Medium Risk, and Low Risk. Tapes in the Very High Risk or High Risk categories were: Betacam, M2, 2” Quad, ¾” U-matic, and 1” Type C. Formats in the Medium Risk category were: Betacam SP, D1, D2, and D3. Only one format, Digital Betacam, was in the overall Low Risk category.

Preservation options include Migration, in which a new videotape copy is made from an existing master, and Digitization, in which video is encoded, stored and distributed purely in the digital domain. In general, digitization is a more satisfactory solution than migration. This is because digitization eliminates the need for future re-recording, allows for digital restoration of damaged content, and facilitates monetization through greatly improved search, retrieval, and distribution capabilities.

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