RE-LUBRICATION OF COMPACT CASSETTE TAPES WITH SBS (SOFT BINDER SYNDROME)

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1. Introduction

The Alicia de Larrocha Foundation[57], devoted to pianist Alicia de Larrocha (Barcelona, 1923–2009) holds a valuable collection of private audio recordings, mostly non-commercial live concerts and interviews that covers over 60 years.

Following IASA guidelines, more than 500 compact cassettes of all brands and types have been recently catalogued and digitized (04/2013 – 07/2014). Although most carriers were in good optical and mechanical condition and allowed for proper transfer, around 2% of them presented severe degrees of tape-to-head sticking and squealing ("stick-slip[58]"), which resulted in a well-known array of problems:

- The frequency modulation (FM[59]) of the original audio carrier which causes, depending on its extent, from a wobbly flutter effect to complex non-linear frequency sidebands (high frequency artefacts) that cannot be removed once in the digital domain.[60]
- A progressive decrease in the original signal level, especially at high frequencies (low-pass filtering).
- Increased tape-to-head tension and friction that slows down and eventually stops the deck playback transport.

Such problems are as a whole the result of the so-called *Soft Binder Syndrome* (SBS)[61] to substitute what was formerly known as *Loss of Lubricant* (LoL).

The goal of this article is twofold:

- To review key theoretical aspects of SBS as a result of FM distortion and analyse its effects on the digitized frequency response of some affected cassette tapes.
- To present a practical implementation for individual tape re-lubrication which, based on past reported experiences,[62] sometimes combined with cassette shell re-housing, has given good results for renewed playback and digitization in the short and midterm.

This re-lubrication proposal is based on a standard tape transport speed-controlled with an Arduino[63] motor shield processor that is able to provide continuous and even lubrication to tape as it travels in an external path around a rotating foam drum flooded with cyclomethicone, a volatile siloxane that completely evaporates with time. Playback equipment for the re-lubricated tapes (Nakamichi CR-7 and ZX-7) remained undamaged in the mid/long term.

57 www.aliciadelarrocha.com.
58 In a similar way a bowed string would trace a saw-tooth-like vibration, the stick-slip tape movement causes a saw-tooth-like kinetic friction variation that shifts up and down the originally constant transport speed, frequency-modulating the resulting voltage induced in the playback head.
59 "In contrast to linear modulation, exponential modulation [such as FM] is a nonlinear process; therefore, it should come as no surprise that the modulated spectrum is not related in a simple fashion to the message spectrum" (Carlson 2002:18).
60 Due to the sidebands produced by FM modulation, this disturbance can mistakenly remind of a sampling clock error in the digital domain where aliasing distortion was present.
61 A term defined by Richard Hess -see Hess, R.(2007:251)- and recalled by FACET (2007:46).
62 See Hess (2007:260) and experiences by Marie O'Connell quoted at http://richardhess.com/notes/2006/03/09/wet-playing-of-reel-tapes-with-loss-of-lubricant-a-guest-article-by-marie-oconnell/.
63 See http://www.arduino.cc/.

2. SBS, SSS, LoL: the problem and the terminology in context

"Soft Binder Syndrome" is broadly accepted as a catchall phrase to describe several problems related to hydrolyzed polyester urethane binders (including lubricants) and consequently to different and faulty tape behaviours:

- SSS ("Sticky Shed Syndrome"), mostly referred to polyester back-coated tapes that may show any combination of stickiness, shedding, and/or squealing that *can* be temporally reduced by backing (aka tape incubation).
- LoL ("Loss of Lubricant"), a term being historically applied to polyester-based tapes that will squeal due to the stick-slip traction provoked by stickiness, but mostly without oxide significant shedding, and which *do not* respond positively to backing.

It has been shown that, in normal conditions of use and storage, magnetic tape is not prone to lose its original amount of lubricant, even though exhibiting SSS or SBS. Following Hess terminology, the FACET document proposes SBS-UP (Soft Binder Syndrome — Unidentified Problems) as a way to particularly refer to this formerly misunderstood "Loss of Lubricant."

Analogue cassette tape (from 1963 on) may exhibit this SBS-UP (and not SSS) due to the following facts:

- Polyester urethane binders were used.
- Although it is always polyester based, tape was not back coated (coating being closely related to SSS).
- Tape may show stick-slip and squealing problems, but not oxide shedding.
- Reportedly[64], cassette tape has never responded positively to incubation.

If incubation is discarded as a temporal solution, and if actual lubricant loss is dismissed as the main reason for SBS-UP, then which approaches remain?

2.1 Cold playback

Instead of acting on the tape, Hess and others propose to adapt the environment for a controlled cold playback, were low temperature — below the so-called glass transition temperature Tg — would reduce stick-slip noise modulation. In favour of this approach there is the experienced fact that SBS increases with working temperature, that is, after the reproducing machine has achieved its normal working temperature (which may be especially high in cassette decks). The author has not yet tried or found any case studies of this approach specifically applied to cassette tapes and players, but Hess has tested it on open-reel tapes.[65]

3. Lubrication, again

Discounting actual loss of the original lubricant, its degradation or failure to work as intended might be one of the reasons for a failure playback. Based on re-lubrication, temporal solutions have been devised to reduce friction by temporally smoothing tape-to–head wear while minimizing spacing losses (HF response decay).

Re-lubrication should then be considered not as a way to compensate for a material loss, but to recover the ability of transporting the tape smoothly through its path.

Several lubricants have been reported as possible candidates,[66] among which the author considered two:

64 See Hess, R. (2008:256).
65 See Hess, R (2008: 253-253).
66 See Hess, R.(2008:258).

- Jojoba oil, a 100% vegetable oil obtained through cold pressing of the seeds of the *Simmondsia chinensis*.
- Cyclomethicone pentamer, a volatile, non-greasy, low viscosity silicone oil (also known as decamethyl, cyclopentasiloxane cyclopentasiloxane).

Cyclomethicone has been preferred for the following reasons:

- The existence of previous successful experiences, specifically on cassette tapes.[67]
- No need of dilution with isopropyl alcohol, which reportedly swells the binder and makes it softer.[68]
- The assurance of volatility after a certain amount of time, which means that the silicone will fully evaporate in the mid-term, long after digitisation has been made possible.

Image 1. Cyclomethicone and Jojoba oil.

This final point must be overstated, as any additional lubricant will not be absorbed by the binder and thus should be removed, spontaneous vaporization being the ideal solution.

67 See Hess, R. (2007:260) specific approach for cassette tapes.
68 See Hess, R. (2007:259).

4. Practical implementation

As the total amount of cassettes affected by SBS in the Alicia de Larrocha Archive was not critical, a simple, one-at-a-time method for cassette tape re-lubrication was devised to allow for a motorized, smooth, uniform application of the lubricant over the whole tape width and length *outside* the cassette deck, avoiding the need of electromechanical modifications.

A prototype was built based on the following elements:

- One *Arduino Due*[69] microcontroller board, plus *Arduino motor shield processor*
- One standard cassette tape transport (motor included) un-mounted from a portable cassette player
- One rotating foam drum flooded with cyclomethicone, able to lubricate tape continuously and evenly as it travels in an external path

The actual implementation could not be simpler. The Arduino microcontroller is programmed through a computer laptop to control the rotating time, speed, and, eventually, direction of the standard transport motor (real-time forward playback speed used). The foam drum is heavily flooded with the synthetic lubricant and remains fully wet throughout the length of any tape; being lightly-weighted, it sticks to tape and rotates along by static friction on its axis, avoiding the need for a synchronic motor.

The prototype, mounted on a soft plywood board, allows for adjustable pins or hooks to specifically house any cassette and provide the easiest and smoothest path around the foam drum. When needed, a specific pin is oriented towards the pinch roller to add a slight pressure in order to maintain tape-to-roller contact for steady tape transport.

Such a solution avoids the need to extract the tape from its cassette shell to apply re-lubrication, so welded shell tapes (with no screws) are not damaged.

69 Arduino is an open-source electronics platform based on easy-to-use hardware and software, intended for the implementation of all kinds of interactive projects. See http://www.arduino.cc.

5. Affected tapes

Table 1 shows actual tapes (brands and types) found with severe degrees of SBS-UP. Their production years significantly coincide around 1970-1980.

	Cassette brand & model	Production years*	Type	Problem	Diagnosis
1	BASF SM cassette LH super 120	1974-75	Type I	squealing tape (stick-slip)	SBS
2	Philips SuperFerro High Output LN C-90	1978-81	Type I	squealing tape	SBS
3	Philips SuperFerro High Output LN C-90	1978-81	Type I	squealing tape; progressive HF signal loss	SBS
4	TDK Low Noise C120	1975-78	Type I	squealing tape	SBS
5	BASF SM cassette LH super 90	1974-75	Type I	squealing tape; wow and flutter	SBS
6	AGFA-GEVAERT C90+6 HIGH DYNAMIC	1975-77	Type I	cassette stops; too high tape tension and friction at the tape head	SBS?
7	Scotch C-90 Extended Range Low Noise High Density	1971-73	Type I	squealing tape; wow and flutter; could not be rewound/played back	SBS
8	unknown - unbranded		Type II	severe wow	SBS
9	Philips Super Ferro floating foil SECURITY High Output LN	1987-81	Type I	increasingly squealing tape	SBS

Table 1. List of tapes from the Alicia de Larrocha Archive affected by SBS.
* Referred by http://vintagecassettes.com/.

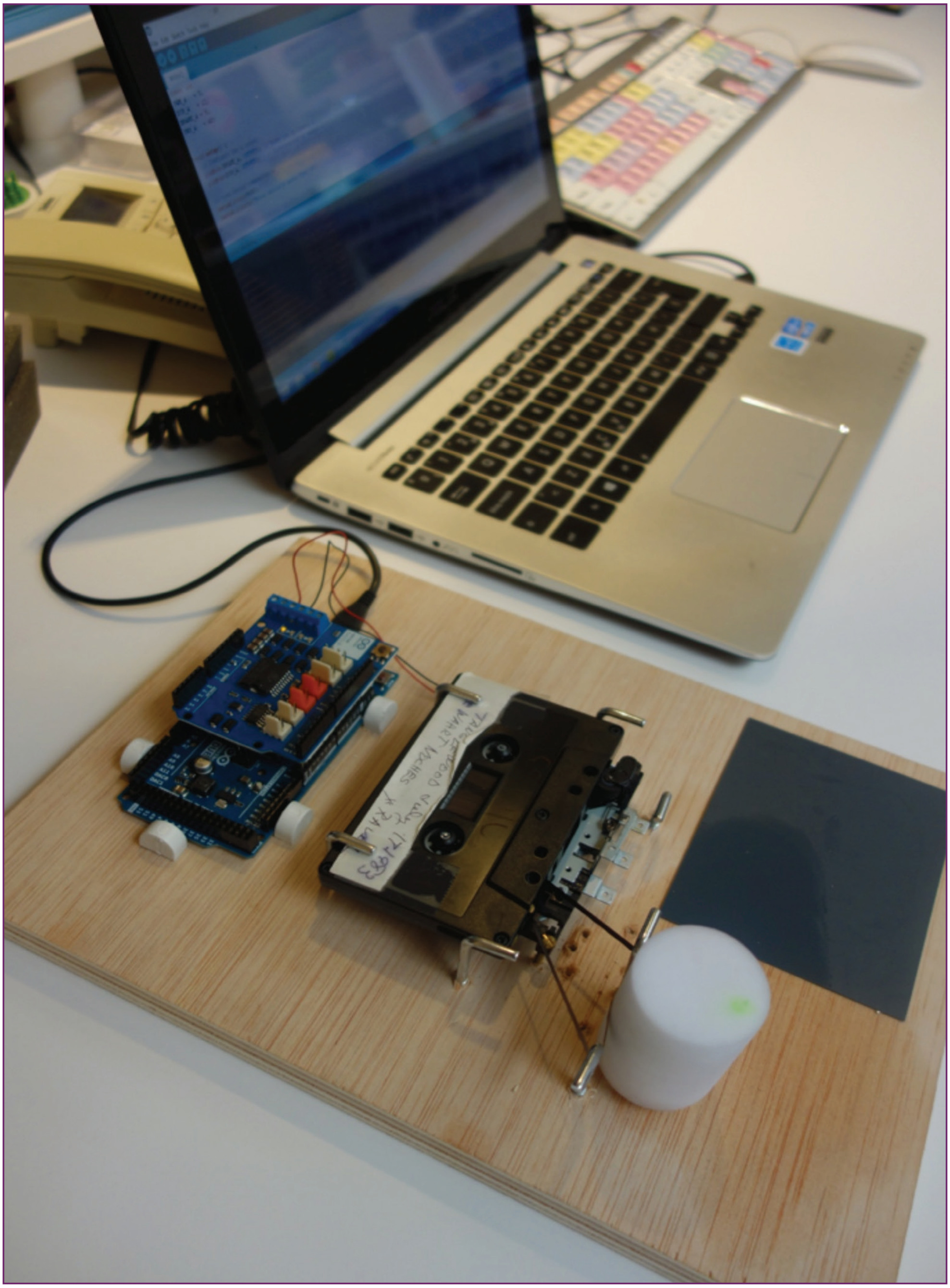

Image 2. Re-lubrication device prototype. Tasso Laboratori de so.

6. Case reports: frequency analysis and re-lubrication results

Re-lubricated tapes were played back and digitized within the next 24 hours to ensure action before lubricant evaporation. Results were satisfactory in all cases, even though a second pass was needed for the cassette tape corresponding to Case 1.

Two study-case examples, Case 1 and Case 2, can be heard at http://www.tasso.cat/en/re-lubrication-of-compact-cassette-tapes-with-sbs/. No post-production processes were applied whatsoever. A videographic example of the working prototype is also provided.

6.1 Case 1: a fragment from Tape nº7 (Table 1)

As sonic and graphical evidence, we will analyze a 75-second sample of the Chopin Piano Concerto nº2, played by Alicia de Larrocha with Orquestra Ciutat de Barcelona (former OBC) conducted by Antoni Ros-Marbà on April 17, 1971 (live recording). The sample was recorded in tape nº7 (see Table 1).

Figures 1 and 2 show the sonogram and the superimposed waveform of this musical passage, pre and post re-lubricated. Vertical axis shows frequency in a logarithmic scale. Beyond the extended high frequency noise along the timeline, highlighted high frequency modulated side-bands are especially revealing. Such inter-modulated ascendant and descendant artefacts are the side effect of a musical phrase where the solo piano plays ascendant and descendant scales. Such artefacts largely disappeared from Figure 2.

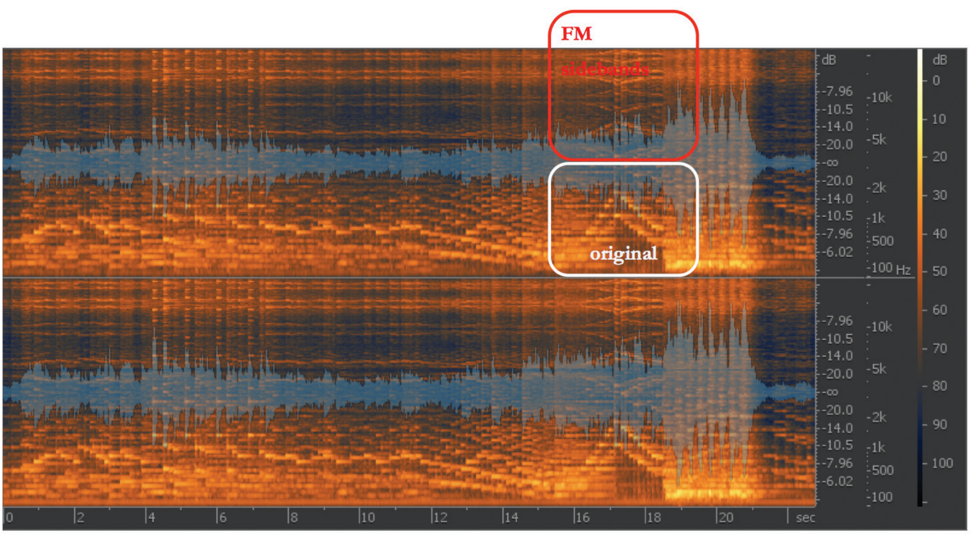

Figure 1. Case 1 pre-lubrication spectral analysis.

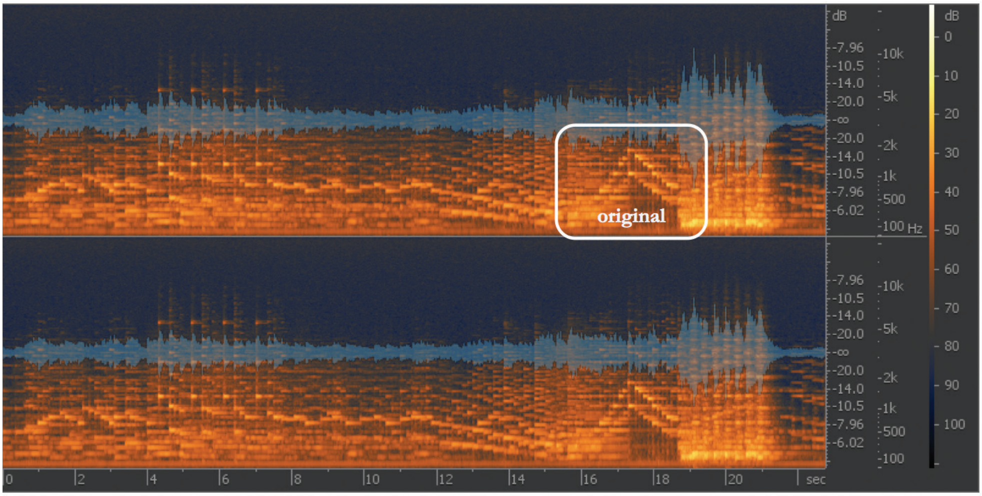

Figure 2. Case1 post-lubrication spectral analysis.

Figures 3 and 4 allow for a closer look at a linear-scale sonogram70 of the same musical fragment. Figure 3 reveals several side band replicas of the original content (centred at f_c) at frequencies $f_{sb} = f_c \pm nf_m$ (where n=1,2,3...) and spaced at multiples of f_m.

Based on analysis of the sonogram data, the original baseband — the spectrum of the original audio carrier — is frequency modulated by the stick-slip distortion at an approximate modulation frequency of f_m = 4920Hz (a period T_m = 0,203ms).

A mild stick-slip distortion would result in a scrape flutter (musically speaking, a wobbly vibrato, as can be heard in Case 2), whereas severe distortion (high amplitude stick-slip as in Case 1) will generate a very complex spectral pattern.

70 Obtained with Sonic Visualiser (www.sonicvisualiser.org), 2048 samples per window.

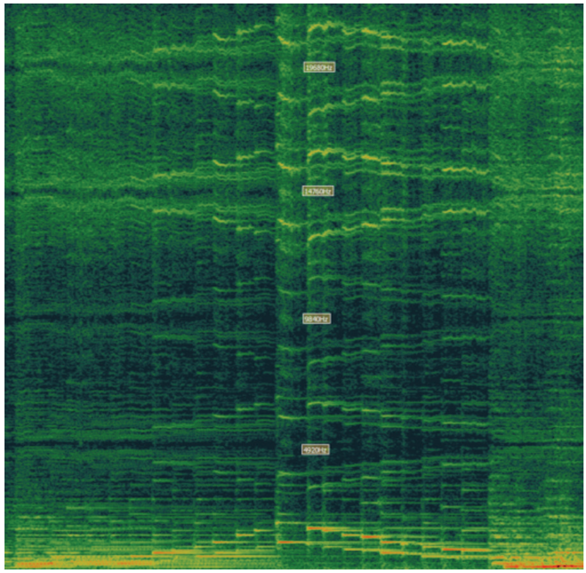

Figure 3. Case 1 pre-lubrication. Baseband and FM at multiples of around 4920Hz.

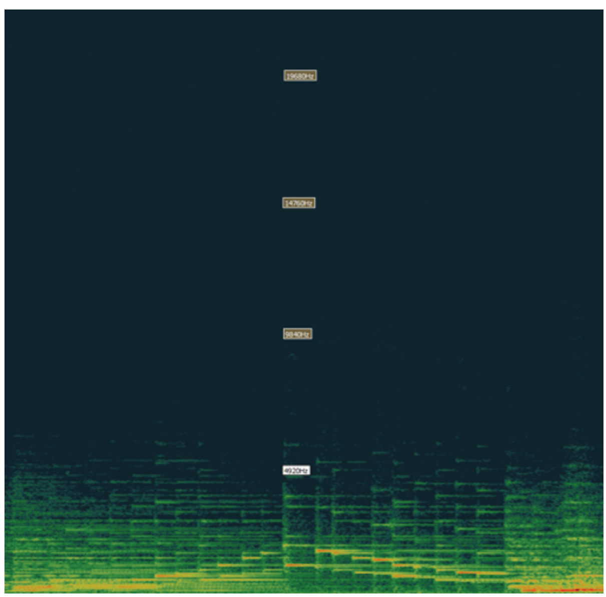

Figure 4. Case 1 post-lubrication. Baseband without traces of FM modulation.

6.1.1. The evolution of FM distortion during playback time

It can be also interesting to analyze the evolution of the modulation frequency thorough the length of this particular tape number n°7 (45min per side — see Table1). This will be related to the ability of the original lubricant to provide smooth tape transport as much as to related mechanical factors such as the tape-to-head friction, the tape tension, the sturdiness and stability of the tape transport, and the working temperature of the cassette deck, among others.

Figure 5 traces the evolution of FM distortion, very low at the beginning, varying during a certain amount of time (see the initially wavy pattern for f_m) but finally severe and roughly constant. In any case the distortion cannot be supposed constant throughout the tape, as, for instance, modulation distortion is quite low and inaudible between minutes 0:00 and 02:30 as well as between 13:00 and 14:00, but almost constant and steady from around minute 23:00 on. As expected, passages with no recorded sound imply no FM distortion.

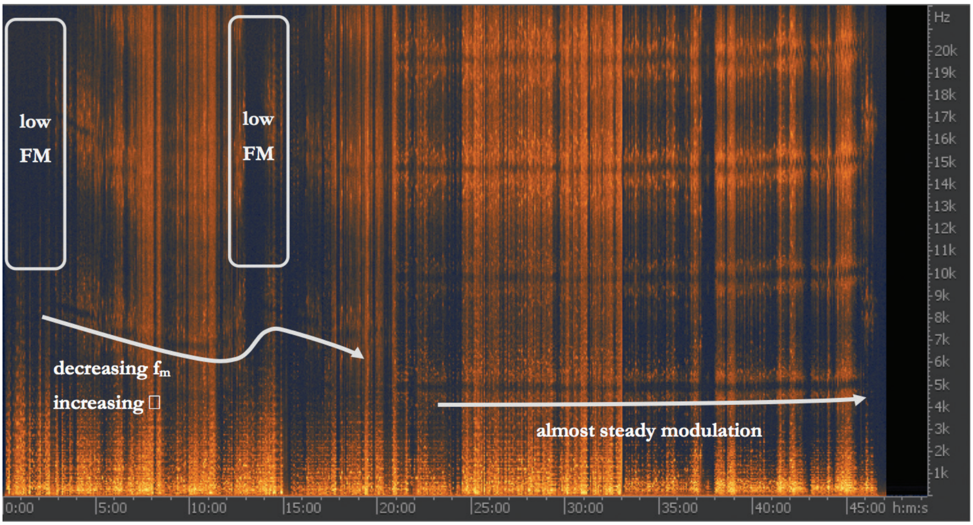

Figure 5. Case 1. Evolution of the modulator frequency fm through time. Pre-lubricated tape #7, side A, channel left (mono).

FM theory states that the extent of the distortion index (in our case, the stick-slip effect) will depend on the modulation index β, which in turn depends on the modulator frequency f_m and the carrier's peak frequency deviation Δf_c (the latter depending on the modulator's amplitude A_m). The modulation index will also define the modulated signal bandwidth (BW), that is, the extent of the side bands throughout the spectrum.[71] These main relationships are compacted in the following equations:

- The modulation index: $\beta = \frac{\Delta f_c}{f_m}$
- Carson's bandwidth rule: $\mathrm{BW} = 2f_m(1 + \beta)$

We can deduce from these equations that, the lower the modulator frequency f_m,

- the higher the original tape-to-head friction and the greater the potential tape damage due to excessive tension build-up,
- the higher the modulation index and so the deeper its audible effect , and
- the higher the bandwidth of the modulated signal and so the more difficult to filter out by conventional means in post-production.

Even though not readily visible in the sonogram, the extent of the carrier's frequency modulation Δf_c (that is, the stick-slip amplitude) is the main consequence of this increased tape-to-head friction and thus the increased modulation index β.

71 For an approachable introduction to FM, see http://www.soundonsound.com/sos/apr00/articles/synthsecrets.htm.

6.2 Case 2: a fragment from Tape nº5 (Table 1)

The following is a 36-second sample of Mozart's Piano Concerto 25, K503 played by Alicia de Larrocha at Avery Fisher Hall (NY) on November 12, 1980 with the Philadelphia Orchestra, Ricardo Muti conducting. The sample was recorded in tape #5 (see Table 1).

This live recording was produced nine years after the previous one, but recorded to a fairly old tape model for the time (a BASF SM cassette LH super 90) known today to be prone to SBS. The stick-slip effect is reflected here in a very audible flutter distortion, even though the modulator frequency is not as severe and defined as in Case 1. Again, re-lubrication reduced tape-to-head dynamic friction and allowed for a smoother playback, resulting in a more stable outcome.

6.3 Negative side effects

Even though overall improvement in sound quality was consistent after re-lubrication, some drawbacks were detected:

- After a second-pass re-lubrication, a slight decay in HF response was audible, even with some dropouts, due perhaps to excessive distance loss.[72] Such dropouts were reparable in the digital domain, but eventually disappeared during a second playback.
- Continuous playback of re-lubricated tapes on the same tape deck, a Nakamichi ZX-7,[73] eventually affected tape transport that resulted in a temporal playback failure that lasted for one week. After extended intervals with the device switched on, to maintain internal temperature and favour lubricant vaporization, the deck recovered normal function.[74]

6.4 Four months after re-lubrication

In order to verify lubricant vaporization, an informal playback test was conducted four months after re-lubrication. As expected, all tapes exhibited varying degrees of the original SBS problem, a fact that confirms re-lubrication only as a temporal solution for proper digitization.

7. Conclusions

Discarded backing for cassette tapes with SBS, as also any digital means of sound restoration at a post-production stage due the complexity of the distortion pattern, re-lubrication has shown promise as a way to deliver — albeit temporally — playable cassette tapes to digitise.

When planning and implementing a prototype to allow for re-lubrication, care has been taken to ensure the following aspects:

- Added lubricant agents should decrease tape-to-head friction without significant increase of spacing loss (HF loss).
- Being that re-lubrication is a temporal solution, lubricants should vaporize from the tape and tape deck in the short or mid-term without causing damage. Nonetheless, the tape deck might become over-flooded with lubricant and become temporally non-operative.
- Lubricants should be applied evenly and uniformly along the tape length (not using manually applied q-tips) with a motorized, externally controlled transport for duration and speed (that was implemented in our case with an Arduino microcontroller).

72 The loss of head output is proportional to d/λ, where λ is the recorded sound wavelength and d the distance between tape and replay head.

73 This was not the case nevertheless for a Nakamichi CR-7, also used extensively.

74 This problem was also observed by Hess (2007:260) and Dietrich Schüller in a recent article at IASA Journal nº42 - Schüller, D. (2014:35) "Magnetic tape stability: talking to experts of former tape manufactures."

- Tape transport should be done in the least obtrusive way, keeping tape within its cassette (be it the original one, or after removing tape to a new cassette shell).
- Future improvements in the propototype should include guide rollers to reduce friction along the tape transport.

I would like to thank Elena Elía and Maria Ferré, curators from the Alicia de Larrocha Archive, as well as Alicia Torra de Larrocha, for their kind support and permission to investigate and show practical examples of tapes with SBS. I am also indebted to Paul Poletti, Perfecto Herrera, and Enric Guaus, professors from the ESMUC Sonology Deparment, for reviewing the drafts of this document. I would finally like to thank Margarida Ullate, Marcos Sueiro and Ferran Conangla for their encouragement to write this document.

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