Time Base Correction: An Archival Approach

by

Benjamin Turkus

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"A compelling national need exists for a Study Center for Video Preservation. Resources allocated to the study of video preservation have been meager relative to the widespread importance of television and video in so many facets of American life. It is as if there were little concern with saving a moving-image record of our history and culture in all their manifestations."

Library of Congress, Television and Video Preservation Report, 1997

I. Introduction

Ampex. Consolidated Video Systems. Sony. NEC. Digital Video/Processing Systems. Television Microtime. Harris. Nova Systems. Prime Image. Hotronic. Edutron. Alta Group. Leitch. ADDA. Snell and Wilcox. For-A. Fortel.

The list of manufacturers of time base correctors and frame synchronizers—not to mention specific makes and models—can, and does, go on and on. But for the analog video formats that require (or greatly benefit from) the stabilizing presence of a time base corrector (TBC) or frame synchronizer during digitization, the selection of TBC/synchronizer is second only to that of the videotape recorder itself.[1] Yet despite the critical roles played by these remarkable, increasingly

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[1] If I'm losing you already, hear me out. My operating assumptions are these:

(1) Capture cards, or video analog-to-digital convertors, are also critical pieces of the puzzle, and should be the subject of their own studies (pertaining to performance, history, processing, etc.), similar to the Federal Agencies Digitization Guidelines Initiative's (FADGI) "Audio ADC Performance Testing" (www.digitizationguidelines.gov/audio-visual/documents/ADC-report_20160127.pdf)

(2) Much can be resolved in the digital realm, post-digitization, but for certain types of time base errors, the TBC still reigns supreme. As James Snyder of the Library of Congress' National Audio-Visual Conservation Center (NAVCC) explained in a recent email:

> Basically the 'garbage-in, garbage-out' principle applies: you can do a lot with digital processing after A/D, but not having the error go through the A/D process in the first place, compared side-by-side with digitally processed uncorrected video after the A/D process, will in most cases look better (as in closer to the original content signal) (Email from James Snyder, Dec. 11, 2015).

(3) While TBCs have often existed as integral parts of videotape recorders (a history that I will trace back to the late 1950s, and simultaneous developments that occurred at RCA and

obsolete machines (some of the earliest of analog-to-digital video conversion devices), their inner-workings remain a mystery to many of those responsible for reformatted video materials.

Speaking at a different time, of a different industry, Bob Paulson, General Manager of Television Microtime, may have said it best in "Time Base Correction—What It Is—What It Does," in the July 1973 issue of *Broadcast Management/Engineering* (BM/E): "'Time Base Correction' is a television industry term which is broadly and loosely used, but little understood."[2] Following this smack-down of an opening remark, Paulson continued, sketching a more detailed portrait: "Jitter, drift, picture tearing, flagwaving, hue shift, skew error, and color streaking"—these are just a few of the time base errors that can be introduced during the "generation, transmission, recording, playback, and/or reprocessing of the video signal," just a few of the artifacts that can vary—at times subtly, yet at times significantly—depending upon one's choice of TBC.[3]

Ampex), they have just as often existed apart, as separate, standalone machines. While I side with the stance that external time base correction is generally an inferior substitute for internal, on-board signal processing, in my work at the Bay Area Video Coalition, much of my time is spent reformatting artist-recorded video on non- or semi-professional formats such as ½'' open reel EIAJ-1 and ¾'' U-Matic. For these formats, internal TBCs were either not developed or were relegated to a single VTR model from a single manufacturer (Sony's BVU-950 for ¾''), making the selection of an external TBC a decisive moment in the reformatting process.

[2] Bob Paulson, "Time Base Correction—What It Is—What It Does," *Broadcast Management/Engineering* (July 1973): CM/E—6-8.

[3] Ibid.

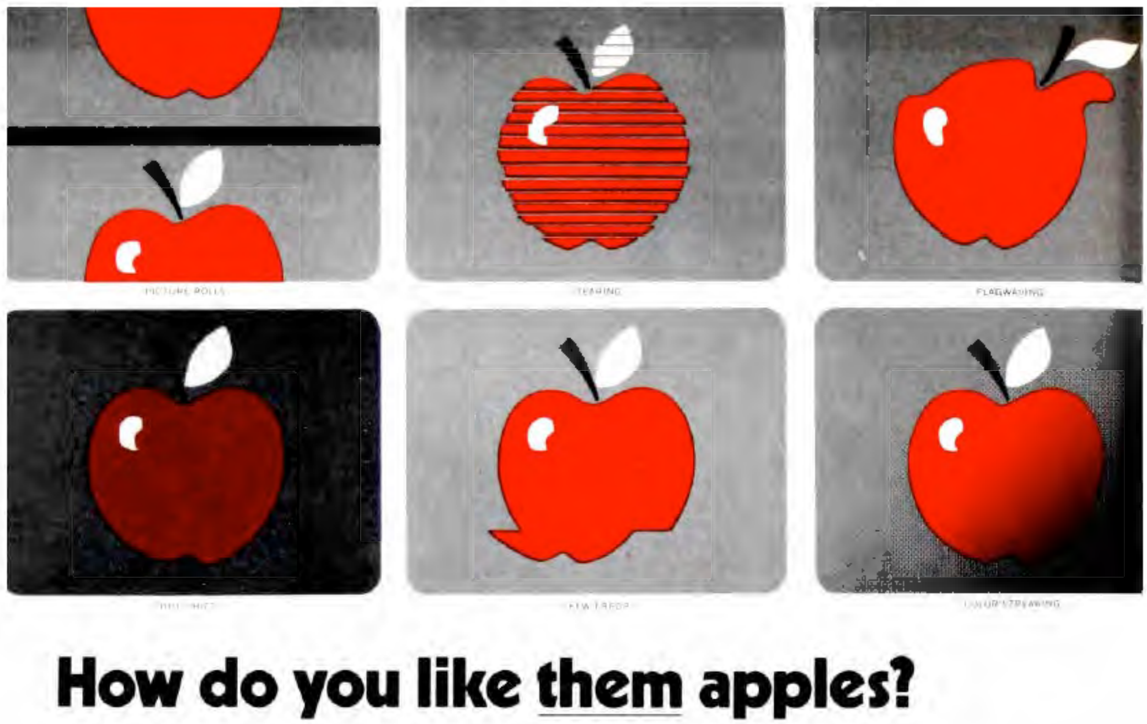

Fig. 1 Television Microtime TBC advertisement, BM/E July, 1973. The text below reads, "Like 'em or not, them apples show composite errors in video signals," errors such as: picture rolls, tearing, flagwaving, hue shift, skew error, and color streaking (www.americanradiohistory.com).

How can (and do) archivists and preservation vendors go about making these all-important determinations? Are there objective criteria (inputs/outputs; operational specifications; internal vs. external processing) or subjective criteria (handling of color; resolution) that factor into this decision-making? If so, which take precedent? And, in a resource-strapped preservation economy, what are the true costs, and practical steps, of procuring a legacy TBC and bringing it to peak preservation performance? If ensuring a TBC's fitness for archival use requires video engineering expertise, what are the ramifications of relying so heavily on a rapidly shrinking pool of video engineers?

Definitive answers to any of these questions may prove illusive. While one might imagine that TBCs are selected only after carefully consideration and consultation, in practice this elemental part of video preservation exists in a hazy gray zone, dominated by anecdotal differences of opinion, surface-level descriptions, and closely held proprietary knowledge. While much can be gained through informal channels (List-servs such as AMIA-L, the Old VTRS Yahoo Group, and the QuadList; community forums such as the AIC's CoOl Conservation, Creative COW and the Digital FAQ), there remains a lack of readily available, practical information, something akin to: "When transferring/having transferred X video format, acquire/ask about Y or Z TBCs."

There has never been a major published study of TBC performance; there is no book devoted to TBC history; no Library of Congress or Federal Agencies Digitization Guidelines Initiative (FADGI) cross-comparison survey. This could be due to the constantly evolving nature of video formats *and* time base correctors—over their fifty-plus year history, TBCs and frame synchronizers have taken all manner of shapes and sizes, from massive units to peripheral component interconnect (PCI) cards—but it might also be an indication of video's doubly-damned status, neglected in an already neglected field. The passage from the Library of Congress' massive two-year study that opened this essay, and the audiovisual preservation community's general inability to galvanize any form of widespread, tangible action in the intervening years, might just say it all—video seems destined to remain a secondary, fringe interest, left with "meager resources" and "little concern."[4]

If anything, though, the need for a National Study Center for Video Preservation is perhaps even more pressing today than it was in 1997. While securing sustainable funding for such an endeavor would undoubtedly be a challenge, much could be gained by returning—and recommitting to—the goals laid out in "Section 4.3" of the 1997 report:

- The purpose of a study center, therefore, would be to collect all relevant resources relating to the technological history of television and video, and to make these resources available to any individual or organization in need of them;
- The center should maintain a comprehensive inventory of obsolete playback equipment in good working order, plus spare parts;
- The center should work closely with restoration laboratories and television engineers and other experts in order to commission tests of videotape binders in an empirical setting outside the considerations or influence of manufacturers; and
- The center should develop and offer a variety of training programs about video preservation techniques.[5]

As tape-based workflows continue to erode, and expertise dwindles, it has become all but impossible to point to any one widely successful analog video-focused

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[4] Library of Congress, "TELEVISION AND VIDEO PRESERVATION 1997: A Report on the Current State of American Television and Video Preservation Volume 1: Report" (1997): 103-4.
[5] Ibid.

initiative capable of matching the recent achievements of similar digital preservation-related efforts (Digital Preservation Outreach & Education; the National Digital Stewardship Residency; the BitCurator Consortium; Digital POWRR). This is not to take away from the great strides or abundant need for such work, but merely to point out that analog video has never—and likely will never—receive the same level of attention or enthusiasm. In a recent email, Michael Angeletti of the Stanford Media Preservation Lab acknowledged the hard-to-quantify, sobering truth: "Occasionally, this stuff [TBC selection, repair, maintenance] comes up for people working outside preservation, but the core group that relies on legacy equipment is very very very small. I think it's even smaller than we think."[6] But despite the general lack of interest, and the often intimidating technical barriers, time base correction remains a rich and worthy subject matter, one that should be relevant to anyone involved in the archival reformatting of analog videotapes, whether that work occurs in-house or by an outside vendor.

Structured as a series of inquiries into time base correction, the two sections of this essay will present different ways for archivists to expand their approach to TBCs. Chapter One, "Why Time Base Correctors?," will address the historical, tracing important developments in TBC technologies, with particular attention paid to the rapid proliferation of digital TBCs in the early 1970s. Reflecting wider shifts in American technology and culture, the story of digital time base correction and frame synchronization is, at its core, the story of advances in neighboring fields (integrated circuit design) aligning with the demands posed by new forms of electronic

[6] Email from Michael Angeletti, Nov. 18, 2015.

newsgathering (ENG). By looking closely at the often-unsung individuals who envisioned ingenious ways to expand the reach of television, counteracting the inevitable imperfections of a system (videotape recording) whose optimal operational mode called for (but could rarely guarantee) complete and utter precision, this technical history will blend patents, trade publications, and first-hand interviews to demonstrate that, as much we may prefer to avoid it, contemporary video preservation will always be inextricably linked to the standards, limitations, and working practices of the broadcast industry.

But if our goal is to understand why different TBCs behave in different fashions, we must first contend with time base errors themselves. Therefore, interwoven within this history will be the video basics that underpin these irregularities of the video signal (VTR mechanical systems, transverse and helical scan recording methods, the NTSC's introduction of color to broadcast television, color-under/heterodyne recording systems, servo systems, and the underlying structure of the composite video signal itself). Just as the root causes of time base errors can be traced back to a variety of interrelated phenomena, mostly tied to synchronization, their "correction" was achieved through different means, in different times, beginning with analog systems (electronically variable delay lines; glass/ultrasonic delay lines, a.k.a. tapped lines) and proceeding toward the advent of digital time base correctors.

Spending time in the once-flourishing world of TBCs, one can't help but reflect on the tenuousness of all legacy video technologies. In Chapter Two, "Correcting a Time Base Corrector," I will turn my attention to the archival afterlives of TBCs, staking a renewed claim for their significance by presenting a case study of my own effort to procure and refurbish a Digital Processing Systems' DPS-295. What began as an eBay steal blossomed into an expensive, half-year saga, but, by staying involved in the process—taking the machine apart, learning how it operates (a little bit), and participating in its repair (a little bit), I walked away with a better understanding of how these machines can be leveraged in the service of our wider mission. The guiding question throughout will be: why have such "peripheral" machines been relegated to the sidelines, denied more extensive investigation and discussion, especially when they play foundational (if little understood) roles in the reformatting process?

Although the do-it-yourself repair mentality is a common thread that runs throughout video history, it seems to stand in opposition to the traditional archival responses to the "magnetic media crisis" (obsolete machines + degrading tapes = we're screwed). But rather than race each other to the finish line, scrambling to raise funds for "massive and rapid digitization" efforts, I will instead suggest that the "crisis" be understood as first and foremost a human problem. By working to bridge the widening technical gulf that separates archivist from video engineer, we might just surprise ourselves, developing new skills and discovering cost-effective, self-sufficient alternatives. While some of the obsolescence factors that affect TBCs are distinct from those affecting VTRs (less mechanical operations means less hard-to-replace moving parts), the case for prioritizing TBC refurbishment is in some ways even more urgent and compelling (fewer skilled technicians, harder to track down service manuals, and longer lasting, more enduring repairs).

Ultimately, what becomes of analog video—this unique manifestation of our history and culture—will depend upon these devices. But, perhaps more significantly, it will depend upon our willingness to explore that which is underneath, that which is not readily visible on the surface of these remarkable machines so often taken for granted.

II. Why Time Base Correctors?

Key Takeaways

- There is no understanding time base correction without first understanding time base errors and, more generally, how television signals are transmitted and recorded onto videotape.
- The swing of TBC history goes from internal, integral part of the VTR, to external, standalone device, to somewhere in-between.
- Internal TBCs provide a less adulterated form of signal processing. However, external TBCs do come in handy—for the formats that require them (½" open reel EIAJ-1), for unusual cases, and for their additional features (heterodyne processing; noise reduction; chroma alignment; dropout compensation, analog-to-digital (SDI) conversion).
- The oldest non-professional video formats require time base correction to be digitized.
- Our understanding of the options available to us depends on our willingness to explore broadcast history.

Time base correction was the ultimate hedge. It was the tolerance built into the system, predicated on a powerful notion—for videotape recording to complete its march to dominance, replacing the film-based kinescope and aligning itself more fully with the bright, expansive future of broadcast television, one of two things would need to occur. Either videotape recorders would need to become so electromechanically precise as to eliminate any form of irregularity, or, a means of compensating for inevitable imperfections would need to be built into the system itself. But outside the sterile confines of the engineering lab, it was known that videotape recorders behave more like human beings: no two machines follow the exact the same path, and no two machines respond to stimuli in the exact same fashion. Devised in the late 1950s, and exploding in popularity in the early 1970s, time base correction might best be understood as one of the unsung players that helped create the conditions for television and video's half century of Galactus-like sprawl; as these media forms grew in technological complexity and reach, it was time base correction that allowed for previously unimaginable new modes of transmission and recovery.

That time base correction also proved to be something of a democratizing force, if, a contingent and contained one, is one of the central ironies of this moment in television and video history. Opening the doors to broadcast by transforming "lesser" video signals into those capable of meeting regulatory standards, time base correction became, in a manner that would likely have surprised its own creators, a tool for social change, providing a select group of artists and activists with a means of insinuating themselves (and their portable video visions) into American living rooms. In *Subject to Change: Guerrilla Television Revisited* (1995), Deirdre Boyle distills the history of alternative video in America into a potent two-sentence brew; while she doesn't explicitly mention time base correction, she does direct us to consider how technological advances like TBCs contributed to one of the central contradictions of the early 1970s: the push-pull tension, and cycles of resistance and compromise, that characterized the relationship between "guerrilla" and "mainstream" media makers:

> At first, guerrilla television aimed at creating a distinct, parallel system to broadcast TV but, when that dream proved too difficult to realize, it turned into a reform movement to 'remake' television into something new, vital, peculiarly electronic, and responsive to the needs and expectations of a generation raised on this medium. In the process, guerrilla television became entwined within the system it claimed could not be reformed, propelled from

> cable to public to network television and eventually devoured by the parent that spawned it.[7]

In Boyle's more downbeat telling, TBCs were one of the tools that helped usher in an atmosphere of false (or unrealizable) new televisual potential or promise. Coinciding with the rise of portable, affordable video equipment (Portapak cameras and ½'' open reel video, in the mid-to-late 1960s), the standalone TBC of the 1970s allowed artists and activists to overcome the steep technological and regulatory hurdles that had prevented access to the airwaves. These were devices that gave the impression that television could, in fact, be remade, transformed into something reciprocal, something "two-way," something with the power to counteract the "one-way" nature of network broadcast.[8]

For video artist Nam June Paik, the "broadcast standards" that were typically invoked to shut out artist-recorded video were false, hypocritical constructions, made insufferable through their uneven enforcement. In a 1972 letter written to

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[7] Deirdre Boyle, *Subject to Change: Guerilla Television Revisited* (New York: Oxford University Press, 1997), xiv.
[8] Nam June Paik, "How to Keep Experimental Video On PBS National Programming" (June 6, 1979): 3. Available in the Vasulka Archive, at: http://www.vasulka.org/archive/Artists4/NamJP/VideoPBS.pdf

While I have emphasized the transformative potential presented by digital time base correction, it is worth acknowledging that access to expensive, new-to-market TBCs was limited at best. Simply put, these were broadcast tools designed for broadcast hands. The relevance for contemporary archivists, though, is that the legacy broadcast tools sought after by this select group of artists and activists are largely the same tools available for saving commercial *or* non-commercial video today. Yet while digital TBCs may have opened of the doors for some, there were limitations in this moment; as Sara Chapman describes in "Guerrilla Television in the Digital Archive" (2012):

> Although much of the early half-inch movement was marked by an emphasis on critiquing the pervasive and preexisting structures of broadcast television, little half-inch actually found its way to the airwaves. Technical incompatibilities made the direct broadcast of the half-inch video signal an impossibility; this would require first transferring the inexpensive tape to the much bulkier and more expensive broadcast standard controlled by television studios" (*Journal of Film and Video* 64.1-2 (2012): 43).

Radical Software, Paik showed utter contempt for broadcasters' willingness to throw regulations out the window when it suited their own (likely financial) interests:

> We are hearing so much about 'Broadcast standard' in video. But the more important that content is, the technical standard tends to be less perfect…e.g. CBS report on the dissenters in Soviet…and many satellite relays, which tend to lose color sync often…and finally MOON LANDING…Why did the FCC not forbid the broadcasting of the Moon landing?…it was a double standard.
>
> Moon landing killed so-called FCC standard in video technology for good….[9]

In a later essay, from 1979 ("How To Keep Experimental Video on PBS National Programming"), Paik described FCC regulations as a "de facto infringement of the First Amendment," and he pleaded for the American Civil Liberties Union (ACLU) "or some other enlightened foundation" to take up his cause. Yet after wallowing in the "personal agony" of living "under the arbitrary terror of the Vertical Blanking regulation," Paik acknowledged that a technical innovation, one that arose between 1972 and 1979—digital time base correctors—had indeed changed the game, bringing about a less restrictive time through advanced signal processing:

> Although this problem has now been solved by the introduction of new frame buffers in time-base correctors, we must keep vigilant so that no new artificial barriers will be set up to keep the monopoly of the air waves.[10]

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[9] Nam June Paik, "Binghamton Letter [to *Radical Software*]" (Jan. 8, 1972): 126. Available in the Vasulka Archive, at: http://vasulka.org/Kitchen/PDF_Eigenwelt/pdf/126-129.pdf.
Referenced in: Carolyn L. Kane, *Chromatic Algorithms: Synthetic Color, Computer Art, And Aesthetics after Code* (Chicago: The University of Chicago Press, 2014): 63-4.

[10] Paik, "How To," 6.

This was the era in which Rockefeller Foundation funding allowed for the flourishing of artist-engineer collaborations at a select group of public television stations (the TV Lab at WNET in New York; WGBH in Boston; and the National Center for Experiments in Television at KQED in San Francisco). While artists such as Paik quickly recognized the potential of digital TBCs, it was engineers who first grasped their newfound power, particularly when it came to stabilizing the wild signals of ½'' open reel video. Boyle describes the oft-regarded momentous unveiling of the first standalone digital TBC at the 1973 National Association of Broadcasters (NAB) annual conference with mystery, intrigue, and a certain Indiana Jones-uncovering-the-Holy-Grail-style relish:

> In March, the National Association of Broadcasters met in Washington. Attending the meeting were David Loxton, director of the Television Lab at WNET in New York, and John Godfrey, a supervising engineer at the Lab. They wandered around the floor and heard a lot of whispers about suite 311, but nobody could tell them what was there. Curious, they went to the suite and discovered an extraordinary piece of equipment engineered by a California-based company called Consolidated Video Systems. It was the first standalone time-base corrector.[11]

While undeniably significant—the CVS 502 offered a "window of correction" unheard of at the time, signaling only greater things to come, this moment has overshadowed much of what was accomplished prior to it, contributing to a problematic, constrained sense of the possibilities TBCs offer to contemporary video

[11] Boyle, *Subject*, 75.

preservation. By looking further back, to the earliest days of time base correction, we can gain insight into questions of functionality and selection, learning to better think through determinations of the "best" TBC for a particular video format.

A Return to Internal TBCs

A different kind of history is brought into focus when these transformative devices are moved from the periphery to the center. And with this shift, our understanding of how and why we do what we do—saving at-risk magnetic media by serving as caretakers for legacy analog video technologies—can be given greater direction and meaning. The world of TBCs is far richer and vaster than we may at first expect, and it is only by recognizing the present-day potential of these artifacts that we can begin to take full advantage of them.

Fig. 2 A montage of TBC advertisements, from multiple issues of BM/E. Some of names may be familiar, some brand new (www.Americanradiohistory.com).

The pre-digital history of time base correction is relevant inasmuch as it reminds us of the centrality and importance of internal, "closer to the core" signal processing. When we look back at the first TBCs, analog systems designed for Ampex and RCA 2-inch Quadruplex VTRs in the late 1950s, we see internal devices that were integral parts of larger videotape systems. These were not separate, secondary machines, and this should instantly clue us in: when testing VTR/TBC possibilities for more modern video formats, those that may or may not offer internal time base correction, we should favor (though not exclusively) the internal.

Fig. 3 & 4 Two "Internal" TBCs: RCA 2-inch Quadruplex VTR, with TBC modules highlighted in red circle (L); Sony BVU-950 ¾'' VTR, with TBC on extension board (R).

In "Time Base Correction—What It is—What It Does," (1973), Paulson explains that a different impetus guided the design of these original machines. Unlike standalone TBCs of the 1970s, which were developed for a world of multiple (and proliferating) video formats, a world in which digital technologies were allowing for all kinds of video manipulations (editing, special effects, etc.), these early systems were part of a wider effort to prove the commercial tenability of a single video format—2-inch Quadruplex. In this way, time base correction, in conjunction with improved VTR mechanical and servo systems, would prove that video was here to stay, that it had the power to replace the film-based kinescope as the primary means of recording (and time delaying) television broadcasts:

> Manufactured originally by Ampex Corporation and RCA, these time base correction products have only been available as integral elements in the VTR system whose output they are processing. Ampex trade names of INTERSYNC, AMTEC, COLORTEC, and VELCOMP, and the RCA trade names of ATC, CATC, CAVEC, and PIXLOCK, are familiar to early purchasers of VTRs. None of these efforts was directed to developing a stand-alone time base error correction system which would eliminate the time base distortions of any VTR—at minimum cost for any given level of output quality.[12]

The question of internal versus external processing aside, this first phase of TBC development is also relevant for its setting of the stage; so much of what would follow built upon, and remains indebted to, these early advances. And any review of the first "time element compensation" devices must take into account the contributions of single individual: Charles Coleman, an engineer at WBBM-TV (a CBS Chicago affiliate) turned Ampex TBC designer. In an obituary written for SMPTE's *Motion Imaging Journal*, Peter Hammar, former curator of the Ampex Museum of Magnetic Recording, offered insight into Coleman's lasting achievement—the first purely electronic means of counteracting timing irregularities (what was called an Electronically Variable Delay Line, or EVDL, system):

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[12] Paulson, "What It Is," CM/E-6.

> At WBBM, Coleman figured out a set of analog signal processing circuits that stabilized the VTR playback output, largely solving the picture stability and interchange problems. The 'time domain' signal corrector electronically compensated for the geometric errors in the recording as the four transverse-scanning heads reproduced the 32 2-in.-long tracks that formed one frame of [Quadruplex] video. Coleman's device retimed the VTR output to be time-coincident with a stable reference signal that matched the absolute timing of other equipment in a TV facility. His prototype was dubbed 'Coltec'.[13]

If this basic description is not basic enough, the most critical thing to understand about time base correction is that all TBCs—from the Coltec (which later became Ampex's Amtec), to its nearest competitor, RCA's Automatic Timing Corrector (ATC), to every time base corrector that would follow—operate at the same elemental unit of the video signal: the horizontal line, the left-to-right scan of the camera's electron gun, 525 of which make up one complete frame of a television picture.

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[13] Peter Hammar, "Obituary: Charles Coleman, Jr." *SMPTE Motion Imaging Journal* (January 2006): 44

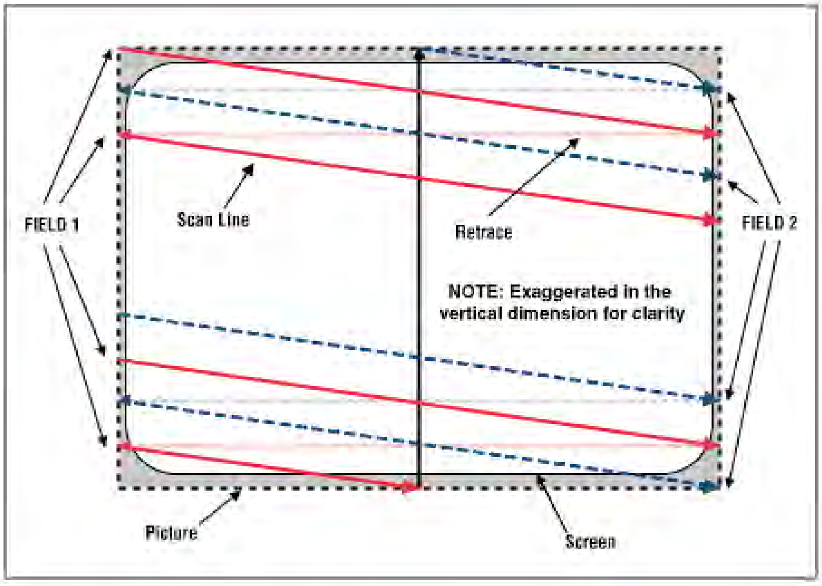

Fig. 5 The TV picture, with scan lines visible (Maxim Integrated Video Basics, www.maximintegrated.com/en/app-notes/index.mvp/id/734)

Intriguingly, despite all of the changes that would follow, the recipe for time base correction was set in this moment. As Coleman himself described in "A New Technique for Time-Base Stabilization of Video Recorders" (1971), no matter how complex the devices would become, the "basic ingredients" would always stay the same:

> The basic ingredients of any time-base corrector are two: first, a time delay device capable of delaying the signal and which can electronically and rapidly change its delay, and second, a means of measuring the time relationship between the video signal and a stable timing reference resulting in a correction signal used to control the delay time of the delay device.[14]

So while time base correction technologies have varied over time, incorporating new advances, responding to always-evolving broadcast tastes, and

[14] Charles H. Coleman, "A New Technique for Time-Base Stabilization of Video Recorders" *IEEE Transactions on Broadcasting* BC17.1 (March 1971): 29.

morphing from analog to digital systems, two things never really changed: the basic principle of delaying lines of video, and time base errors themselves.[15] But to understand time base errors—best described as frequency disturbances caused by tape deformation or mechanical instabilities—one must first grapple with the technically daunting, still-extraordinary technological achievement that was the transmission and recording of television signals onto videotape.

Timing is Everything

When we speak of video, whether analog or digital, we are speaking of the transmission of visual and aural information. Video is an electronic medium, one that flows, moving constantly. Descriptions of its underlying mechanics—"electron guns" and "cathode ray tubes"—have the tendency to make the familiar feel foreign. In *How Video Works* (2007), Marcus Weise and Diana Weynand describe a process that astounds with its speed and immediacy:

> The electron beam inside a video camera transforms a light image into an electronic signal. Then, an electron beam within a video receiver or monitor causes chemicals called phosphors to glow so they transform the signal back into light.[16]

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[15] In *TV & Video Engineer's Reference Book* (1991), S. Lowe provides an answer to that obvious, yet curiously under-discussed question: what about video signals that arrive too late; ones that need to be sped up, rather than delayed? As he explains: "Signals which arrive too early are delayed, while those which arrive too late pass through a reduced delay. *To make it possible to advance some signals, all signals have to be delayed by an amount equal to half the normal maximum error*. The VTR output must therefore be advanced with respect to the reference."

S. Lowe, "Video Tape Recording," in *TV & Video Engineer's Reference Book*, eds. K.G. Jackson and G.B. Townsend (Oxford: Butterworth-Heinemann, 1991): 37/8.

[16] Marcus Weise and Diana Weynand, *How Video Works: From Analog to High Definition* (New York: Focal Press): 15.

Despite their fluidity, their voltage variability, video signals are time-sequential, composed of standardized, discrete units (lines, fields, and frames) that occur in a precise fashion. These units are "frozen" onto tape through an electromagnetic process, to be recovered later through a similar process upon playback. As Aubrey Harris describes in "Time Base Errors and Their Correction in Magnetic Television Recorders" (1961):

> In a magnetic television recorder the electrical waveform is laid down on a tape so that the original time scale is transformed. The recording process allocates each unit of time in the waveform a corresponding unit of space on the tape. On reproducing these recorded elements are converted back into units of time. During the processes of translating the waveform onto and off of the tape, errors in timing may occur which affect the geometry of the reproduced picture and/or its stability with respect to a stable reference.[17]

The notion of the time base—something that can be disrupted, something that may require correction, lies here, in this more structured side of video. Timing is the key to everything in television and video; as Julian L. Bernstein sums up in *Videotape Recording* (1960), "it is an absolute must that during playback, the signal be properly timed, with horizontal sync pulses occurring precisely every 63.5 microseconds [the length of time of one horizontal line, or H] and vertical pulses [which mark the end of a "field" of video, two of which make up a frame] every

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[17] Aubrey Harris, "Time-Base Errors and Their Correction in Magnetic Television Recorders," *Journal of the SMPTE* 70 (July 1961): 489.

16,667 microseconds."[18] In the most basic of senses, sync pulses are the benchmarks by which timing errors, if they occur, are determined.

Looking closer at one horizontal line of video, sync pulses can be broken down into even smaller components, each with its own corresponding microsecond or voltage marker. Most importantly, at the end of each line there is a blanking period (known as the front porch). This is, in a sense, a cool down period and, if it were not provided, the leading edge of sync could be disturbed, resulting in instability.

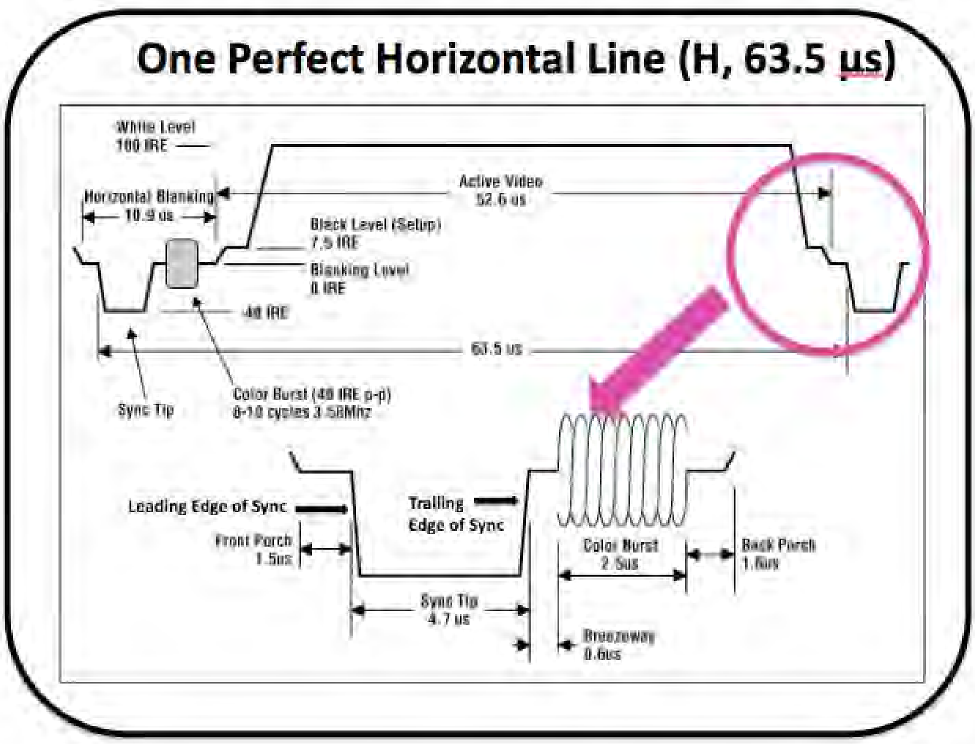

Fig. 6 One Horizontal Line (Maxim Integrated Video Basics, www.maximintegrated.com/en/app-notes/index.mvp/id/734)

As one might expect, the National Television Systems Committee's (NTSC) introduction of color to broadcast television in the 1950s complicated things even

[18] Julian L. Bernstein, *Video Tape Recording* (New York: John F. Rider, 1960): 96.

further, forcing VTR manufacturers to respond in kind, refining their early time base correction systems. In a color signal, each horizontal line also contains a chroma signal and color burst, both of which appear in the vicinity of 3.58 MHz. The color burst in particular serves as a synchronizing reference, and it was by comparing playback color burst to reference color burst that these early systems (Colortec for Ampex; CATC for RCA) were able to perform similar processes of "correction," ensuring that color would remain undisturbed.

While glossing over an extraordinarily complex process, two significant things to remember about the NTSC are: (1) color, as it was squeezed into the monochrome television signal at a high frequency, has an acute sensitivity to time base errors; and (2) the ingenious accommodation at the core of the NTSC moment—the introduction of a color system that would be compatible with the millions of black and white television sets that had already been purchased—lingers throughout television and video history. In *Video Technology* (1988), Gordon White connects the dots, drawing a parallel between the ways in which color was manipulated for television broadcast and the ways in which it was manipulated for recording on low-cost VTRs:

> Not only did the engineers have outstanding success in developing a compatible monochrome and colour television system, but the basic system of transmitting the luminance signal (monochrome picture) separate from the chrominance signal (colour) allowed a variety of coding systems to be

developed and allowed the signals to be modified for the purpose of recording on low-cost video tape recorders.[19]

Bringing it back to time base correction, in *VCR Troubleshooting and Repair* (1998) Gregory R. Capelo and Robert C. Brenner explain that 'color-under' processing—the separation of the luminance from the chrominance and the down-conversion of the chrominance to a frequency 'below' the luminance in low-cost VTR systems—served two distinct, though interrelated purposes: (1) it was an early method of minimizing time base errors; and (2) it decreased "tape speed requirements, equipment complexity, and tape costs."[20] Color-under processing was both economical and effective, and as Koichi Sadashige explains in "Overview of Time-Base Correction Techniques and Their Applications" (1976), the color-under technique was one of the "significant technical developments of VTR technology," enabling "a VTR system to use a relatively low head-to-tape velocity and yet obtain a high-luminance signal-to-noise ratio, coupled with a good chrominance linearity and a low level of moiré."[21]

The relevance for contemporary video preservation is that depending on the video format (½'' EIAJ-1 color, 3/4'' U-Matic; Video8, Hi8, VHS, S-VHS, and Betamax are all color-under systems), and the capabilities of the VTR and TBC being employed, the off tape video signal can be routed in ways that will affect its overall quality. It can either: (1) be sent through the TBC's internal heterodyne color circuit,

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[19] Gordon White, *Video Technology* (London: Heinemann Professional Publishing, 1984): 10-11.
[20] Gregory R. Capelo and Robert C. Brenner, *VCR Troubleshooting & Repair* (Boston: Newnes, 1998): 160.
[21] Koichi Sadashige," Overview of Time-Base Correction Techniques and Their Applications," *SMPTE Journal* 85 (October 1976): 789.

where the time-base error of the luminance signal will be given to the chrominance signal; or (2) it can bypass this heterodyne circuit, and the color subcarrier signal can sent separately (and directly) from the TBC to the VTR. This second method is referred to as the "subcarrier feedback technique," and it allows color-under systems to be processed in manner similar to "direct color" systems (such as 1" Type C).

Subcarrier VTR inputs (SC In) are mostly found on ¾'' U-Matic VTRs, and proper set-up can be a challenge, as different TBC manufacturers have different ways of referring to the direct color process:

- The Sony BVT-800 TBC offers SC DIRECT and PROCESS modes; while
- The DPS-295 offers DIRECT and HETERODYNE modes

Ultimately, the less processing performed by the TBC, the higher the resolution and the better quality.

The Root Causes of Time Base Errors

Returning to the time base, the question is: how does timing—the precise arrival of these synchronizing beats—get screwed up? In "Digital Time-Base Correction for Video Signal Processing" (1976), David E. Acker and Richard H. McLean offer one clue, reminding us that videotape recording is, at its core, a process of "stretching or compressing" the video signal onto tape. In this way, time base errors can be thought of as "elastic variations in the signal."[22] Keeping it relatively simple, Acker and McLean break the causes of time base errors down into three broad categories:

[22] David E. Acker and Richard H. McLean, "Digital Time-Base Correction for Video Signal Processing," *SMPTE Journal* 85 (March 1976): 146.

- Tape dimensional changes
- Mechanical imperfections and intolerances
- Servo considerations in VTRs[23]

But, as with everything video-related, there are always additional levels of technical complexity that can complicate one's clear understanding. The relationship between lines, tracks, sync pulses, and servo systems is particularly complicated, and it is worth taking a moment to consider the strange, at times contentious relationship between an elastic medium and a precise recording process.

During recording, the video signal (video tracks, audio tracks, a control track, and sync pulses) is written onto the tape as it moves around the video head drum.

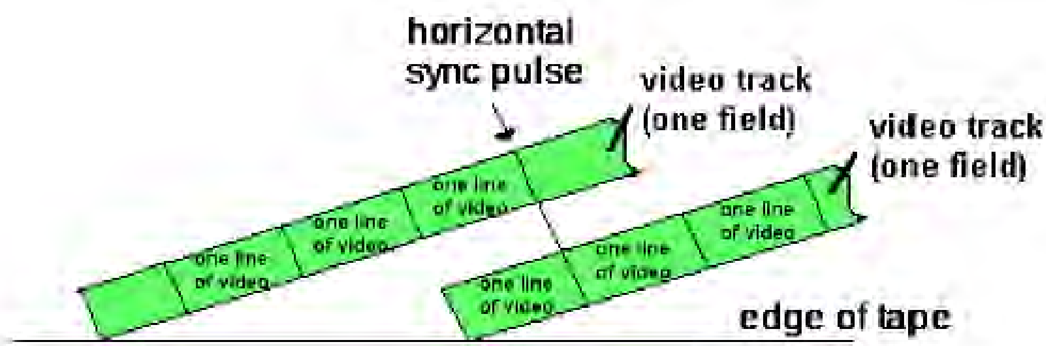

Fig. 8 Close up of video tracks, with sync pulses and lines of video highlighted (danalee.ca/ttt/video_recording.htm)

In effect, this information is recorded as the tape is in a state of being stretched or pulled. After it leaves the drum, the tape's elasticity reverts back to its original state. For the video signal to be read back correctly, the tape needs to be stretched the same way it was during the recording process.

[23] Ibid.

Servos are "self-correcting" electromechanical devices that were designed to ensure that this process happens in as smooth and controlled a manner as possible. They accomplish this by adjusting the speed of two essential VTR motors: the capstan motor, which pulls the tape through the VTR, and the head drum motor, which controls the rotation of the video heads.[24] Much like early time base correctors, servos were developed in the late 1950s/early 1960s to resolve errors related to timing, the inevitable imperfections that occur during recording and playback.[25]

A line up of the problems that servos and TBCs were designed to overcome reveals many areas of overlap; Sencore's Tech Tip #176, "How Servos Work," lists the following "mechanical factors" that benefit from the presence of servos:

- Varying friction between the heads and the tape;
- Variations in tape speed;
- Stretching of the tape; and

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[24] Dana Lee, "Television Technical Theory Unplugged, Version 5.0," 2004, http://www.danalee.ca/ttt/video_recording.htm

[25] In "Videotape Systems Theory," (2004), one of the best concise technical histories of videotape recording available, Tim Stoffel offers a succinct description of the roles served by servos during recording and playback:

> The servos serve to keep everything constant at the correct speed during recording. The servo system also generates a signal that is recorded onto a longitudinal track on the tape, called the control track. The control track serves as a reference for the servos on playback, so the track can be found on the tape. During playback, the servos are much busier. The drum servo is looking at the timing of the vertical sync, and adjusting its speed to keep it constant. The drum servo also has to adjust headwheel position to start scanning a video track at its beginning. The capstan servo looks at the control track pulses, and adjusts tape speed to put the video tracks under the rotating heads.

www.lionlamb.us/quad/theory.html

- Variations in power supply voltages, tape tension, motor bearings, and mechanical wear;[26]

While Patent No. 5,019,906, "Time Base Corrector Memory Arrangement and Memory Control" (1990), written by Jan S. Wesolowski for the Ampex Corporation, offers a near identical list of the root causes of time base errors:

- Expansion or contraction of the magnetic tape after the video signals have been recorded thereon;
- Variations of the speed at which the magnetic tape is driven during the playback mode from that during recording;
- Variations of the speed at which the record-playback heads scan the magnetic tape during recording and playback modes;
- Intentional operations which cause a change in tape speed during reproducing relative to recording such as still frame, fast forward, slow motion, forward shuttle, reverse shuttle, etc.[27]

From the perspective of contemporary video preservation, understanding that time base errors are primarily the result of tape deformation and mechanical instabilities leads to an important conclusion: the resolution of time base errors must involve a variety of activities, including tape conservation treatments (baking, cleaning) and mechanical fine-tuning. While finding the right TBC can be critical, in truth it is only one small part of a much larger equation. Without first resolving all

[26] Sencore, "Tech Tip #176: How Servos Work" http://studiosoundelectronics.com/Vcr%20Servos.pdf
[27] Jan S. Wesolowski, "Time Base Corrector Memory Arrangement and Memory Control" (Patent No. 5,019,906 1990): 1

mechanical issues, any attempt to deal with electronic signal processing (especially that which occurs in a separate machine) is backwards, and will likely be futile.

The Lure of the Tape Economy: ENG and the Rise of Digital TBCs

In the period before digital storage became a possibility—in the age of 2-inch Quadruplex—EVDL systems, combined with improved servo systems (Ampex's Inter-Sync and RCA's Pixlock), provided more than adequate levels of correction. Using "fixed inductors and voltage-variable diode capacitors [varicaps]," EVDL systems compared incoming horizontal and vertical sync pulses to those of a stable reference (studio/station sync generator), compensating for original timing errors by delaying lines of video.[28] Though Quadruplex was a "finicky format," one whose VTRs required regular upkeep, its generally excellent mechanical configuration and much closer to perpendicular track configuration (when compared to helical scan recorders) naturally kept time base errors within the window of correction (±1 μsec.) offered by these first TBC units.[29]

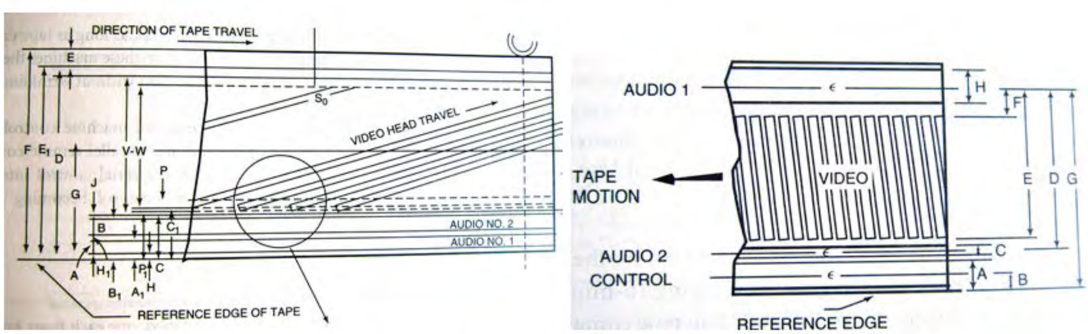

Fig. 9 & 10 Side-by-Side of Helical (L) and Transverse (Quad, R) track configurations (The Electronics Handbook, ed. Jerry C. Whitaker (Beaverton, Oregon: CRC Press, 1996: 1419-1421).

[28] Coleman, "New Technique," 29.
[29] Stoffel, "Videotape Systems Theory," www.lionlamb.us/quad/theory.html

Histories of time base correction typically jump straight from analog EVDL systems to the release of the first digital TBC by Consolidated Video Systems in 1973, but, as with most analog-to-digital technological transitions, there was an interesting hybrid moment between these two periods. These in-between systems—variously referred to as "glass," "ultrasonic," or "tapped" delay lines—worked by joining together delay lines in a sequence, growing the ±1 μsec window of correction in binary leaps (1, 2, 4, 8, 16, 32 μsec, etc.). Again, Coleman was a pioneer of these advances, which blended analog circuits and early digital sensors; in "A New Technique for Time-Base Stabilization of Video Recorders" (1971), he describes his work:

> The principle is as follows. If one has a collection of fixed delay lines, each of whose delay is exactly twice that of the preceding one, and if they can be connected in a cascade utilizing any desired number of lines from the array, then the total delay that be thus obtained can have any value from zero (with no delay in the path) to a maximum equaling the sum of all delays (when all are used) in unbroken increments equal to the size of the smallest delay.[30]

Yet even at their most expansive, delay lines were bulky, impractical, and had windows of correction that maxed out somewhere near 1 horizontal line (63.5 μsec). This was not even close to providing the level of stability needed to synchronize television signals from diverse sources (the dream of broadcasters), or the level of stability needed for helical scan recorders, which, due in part to their longitudinal track configuration and portability (imagine someone running down

[30] Coleman "New Technique," 31.

the street with a forty-pound VTR strapped their shoulder), required a window of correction somewhere between 1 and 100 horizontal lines.

In the early 1970s, rapid advancements in signal processing electronics provided new ways to digitize and store television signals—for correction, but also for editing, for special effects, and for general manipulation. Helical scan recorders were already cheaper, and more portable, but it was in this moment that broadcasters were finally able to envision the potential of helical scan VTRs. As Acker and McLean describe:

> The lure of the tape economy was strong…People who had rejected out of hand the idea of helical-scan VTRs for broadcast use now began to think it would be only a matter of time before the combination of a helical-scan VTR and a digital TBC could produce broadcast-quality pictures. When newer digital TBCs showed improved signal-carrying capabilities and less signal degradation, the movement to acquire helical-scan equipment became a revolution.[31]

While the speed, instantaneousness, and reusability of portable video provided a stark counterpoint to film, which could only be used once and often needed to be processed off-site, the major factor that drove the rise of Electronic Journalism (in CBS' preferred nomenclature, Electronic News Gathering, or ENG), was a financial one. Though not necessarily an unbiased source, Consolidated Video Systems employee Hal Blakeslee's comparison of the costs of film versus video in

[31] Acker and McLean, "Digital Time-Base Correction," 146.

"Time Base Correctors Arrive Just In Time," from the January 1975 issue of *Broadcast Engineering*, offers a sense of the underlying financial considerations:

> For the purposes of comparison, the cost of shooting and processing film for a ten minute television recording would be about $104.00, if a color work print is used. TV News often use original film and the cost is then reduced to approximately $60.00. A Sony U-Matic cassette for a ten minute recording [has] cost of $25.00, can be instantly previewed, and can be erased and reused if the program material is transitory.[32]

Despite its tendency to overshadow much of what came before, Consolidated Video Systems' unveiling of the first commercially available digital TBC at the 1973 NAB conference was an undeniable turning point in TBC history; with a window of correction of ±1.5 horizontal lines (63.5-95.25 μsec), it was clear to many gathered at the conference that the improved storage and processing power of digital technologies would unleash a wealth of new video manipulation possibilities. And from that moment on, it was a flood—at the following year's conference, there were nine manufacturers of TBCs (some of these were analog in nature, but the vast majority were digital).

Differentiating Digital Time Base Correctors and Frame Synchronizers

The relevant questions for contemporary video preservation are: how did digital TBCs actually function, and how can we begin to discern the differences between them? Again, there are few simple answers here; competition bred slightly different ways to get at the same problem, and, as with EVDL systems, nothing was

[32] Hal Blakeslee, "Time Base Correctors Arrive Just In Time," *Broadcast Engineering* (January 1975): 30-31.

static—digital TBCs quickly dropped in price and quickly expanded in capabilities. As Tim Stoffel describes, "The early models could store a single line of video. Soon, two became common. Then 16. Then 32. And eventually, an entire field! ["Infinite window" TBCs]."[33]

But despite their rapid evolution, there remains a core set of digital TBC operations, and to understand these operations, it is helpful to review block diagrams and patents, in particular, one of the first (and one of the simplest): from Consolidated Video Systems, a team of inventors that included Michael Tallent, Lee Scaggs, Ronnie Harrison, and William Hendershot.

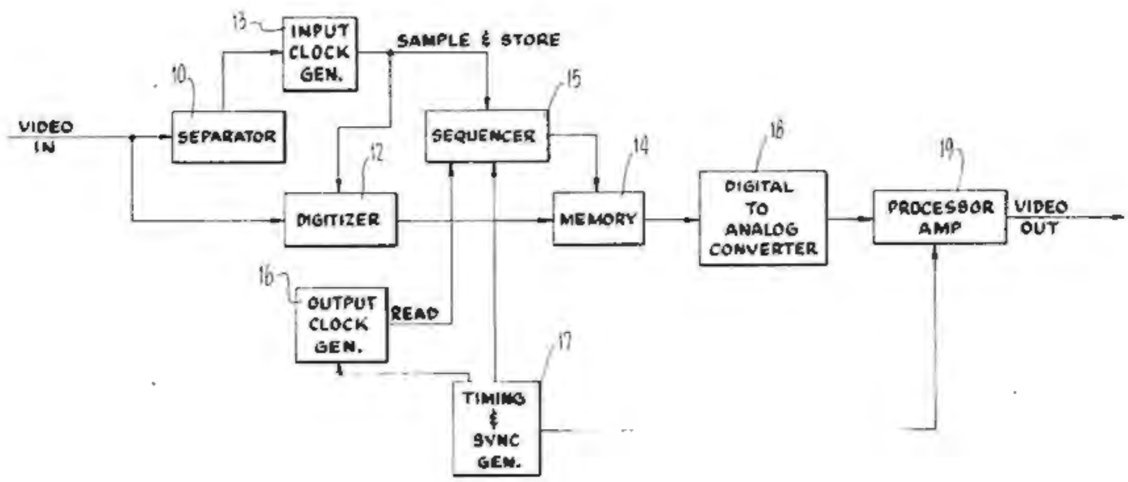

Fig. 11 Consolidated Video Systems Digital TBC block diagram (http://www.google.com/patents/US3860952)

There are three core operational functions of a digital TBC: input processing, memory, and output processing. A February 2003 post to the VideoHelp forum, written by video systems engineer "davideck" (whose user profile offers the

[33] Stoffel, "Videotape Systems Theory," www.lionlamb.us/quad/theory.html

signature, "Life is better when you focus on the signals instead of the noise"), provides a useful analogy and an explanation of how memory functioned in these early digital devices:

> Consider the memory section. It might be a full frame, or just several lines, but in both cases the memory serves as a FIFO [First In First Out] to allow the timing characteristics of the video output to be distinct from that of the video input. Think of memory as a funnel. Video input samples (water) can be added in variable amounts at various times while the output stream remains constant. As long as the memory is not overfilled or emptied, its output rate remains stable.[34]

Memory was, however, just part of the complex processing performed by these devices. From start to finish, a simplified order of operations is as follows:

- First, the digital TBC samples the input video source at a frequency normally three or four times the subcarrier frequency (so roughly 10.7 or 14.3 MHz).
- The sampling clock (the WRITE CLOCK) is locked, and varies, depending upon the off-tape horizontal sync signals, which are stripped from the composite video early in this process).
- The jittery input video is written into memory, typically with 8 or 10 bits per sample (256 or 1024 discrete levels of information, respectively)[35]

[34] davideck, "TBC Fundamentals," *VideoHelp Forum*, Sept. 15, 2005, http://forum.videohelp.com/threads/221219-TBC-Fundamentals

[35] Early memory took the form of either shift registers or Random Access Memory (both of which can read and write at different rates; RAM was superior, though, in that could more effectively read and write at the same time).

- Another clock (THE READ CLOCK), derived from a stable reference (a local sync source or a crystal-controlled internal reference), controls the recovery of data from memory.
- The data is processed, put through a D/A conversion process, and, before it is output, has stable sync, blanking, and burst added back to it.[36]

Frame synchronizers, which also emerged in this era of improved digital processing and memory, followed in the footsteps of the first digital time base correctors. But though they are remarkably similar devices, and can both be used to serve preservation ends, there are important differences worth pointing out. Frame synchronizers were designed to counteract the timing problems that accompanied efforts to incorporate "nonsynchronous sources" into television broadcasts, typically from satellite relays or microwave feeds. Robert Hartwig paints an amusing picture in *Basic TV Technology: Digital and Analog* (2012):

> TBCs are great for correcting the relatively minor errors found on tape, but some video sources are totally out of sync with the studio. For example, when the networks do a football game, do you think there's a cable going from the sync generator on the ground all the way up to that blimp that's getting those dramatic aerial shots? Of course not![37]

A frame synchronizer can be thought of as a TBC with an "infinitely long correction window."[38] Whereas a TBC stores a number of jittery video lines, releasing them with timed precision, frame synchronizers store an entire frame of

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[36] Sony, "BVT-800 Service Manual Theory of Operation," 12324.
[37] Robert L. Hartwig, *Basic TV Technology: Digital and Analog* (New York: Focal Press), 102.
[38] Marc Thompson, "Designing Video Circuits Part Three," *ESD: The Electronic System Design Magazine* (December 1988): 50.

video, holding back or skipping a frame as needed. As Marc Thompson explains in "Designing Video Circuits Part Three," from December 1988 issue of *ESD: The Electronic System Design Magazine*:

> Input to output delay between the two video sources at the output of the frame synchronizer will vary from zero to one full TV frame. At the point where the delay is one full frame, a frame will be deleted. This reduces the system delay back to zero, and the timing error begins to accumulate immediately. If differential timing is in the other direction, a frame will be repeated every once in a while, instead of deleted. In any case, the discontinuity will be only a frame every hour or so, and the viewer will never notice.[39]

The challenge for contemporary video preservation is that, as these digital delay technologies developed, they began to merge, and the waters become a bit muddied with "TBC/synchronizer" hybrids. Occasionally these devices perform both functions, but, on other occasions, it is unclear exactly how they operate. It is quite possible that some synchronizers may be masquerading as TBCs for marketing purposes, and without detailed service manuals and schematics on hand, it can be difficult to determine how the video signal is actually being processed.

Ultimately, if we hope to find the best TBC or frame synchronizer for a particular video preservation application, we must understand not the similarities that these devices share, but rather, their differences. A table that ran in the January 1975 issue of *BM/E*, part of an article called "Time Base Correctors: Now It's a Wide

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[39] Ibid.

Open Field," provides some useful metrics for us to begin differentiating TBCs.

Columns included:

- Make, model, and price
- Window [of correction]
- Stability of output [generally measured in nanoseconds]
- S/N Ratio [a measure of the power of the wanted signal in relation to the noise that tends to interfere with it or mask it]
- Bandwidth
- Differential Gain
- Differential Phase
- VTRs accepted [inputs and outputs][40]

These categories are just the beginning; based upon my research, I would add the following:

- Bit Depth (8 or 10 bits per sample are typical)
- Sampling Rate (3fsc or 4fsc are typical)
- Heterodyne Processing
- Internal Sync Generator
- Dropout Compensation
- Image Enhancement and Special Features

It would seem fitting to conclude this historical review with a modest attempt to answer that most pressing of TBC-related questions, perfectly asked in a

[40] "Time Base Correctors: Now It's a Wide Open Field," *Broadcast Management/Engineering* (Jan. 1975): 54.

two-page Television Microtime advertisement found in the pages of *Broadcast Engineering*:

Fig. 12 Television Microtime TBC advertisement, BM/E January 1975

In truth, there are few hard and fast rules when it comes to TBC or frame synchronizer selection, and it would be naïve to propose a "one size fits all" solution. TBCs reflect their times. They reflect the broadcast preoccupations and technological capabilities of the periods in which they were designed and manufactured. This, coupled with a thorough understanding of operational specifications, is perhaps the most useful way in which we can begin assessing their suitability for contemporary video preservation. When embarking upon such an effort, we must have both a solid methodology for testing, and also a variety of tools at our disposal, including: a broadcast quality monitor (with under scan and cross pulse mode for visualizing synchronizing information), a patch bay or router (for easy switching between TBCs), trusted test tapes, and a calibrated signal generator. And, more than anything, we must have TBCs that are in top-notch, well-serviced condition, which leads to the following chapter, a narrative account of a recent TBC repair adventure.

III. Correcting a Time Base Corrector

Key Takeaways
• As the magnetic media crisis is the result of a series of interrelated events, it calls for a diversity of responses, some of which must include archivists taking up the mantle of equipment repair and maintenance. • Most problems begin and end within the mechanics of the videotape recorder itself. But to resolve some, specifically time base errors, a TBC is still essential. • Without service manuals and schematics, VTR/TBC repair can be a time-consuming stab in the dark. • While some aspects of VTR/TBC refurbishment are likely beyond the capability of archivists, relatively simple electronic repair skills (capacitor replacement)—if tackled in a smart, strategic manner—can be learned, yielding immediate results and saving limited resources. • The repair and calibration of legacy video equipment requires top-notch testing equipment, which must also undergo its own periodic calibration. • The odds of purchasing a ready-to-preserve TBC at auction are slim-to-none. But one can always hope.

It began with a simple recommendation: a Digital Processing Systems' DPS-295 could be a good addition to BAVC's pool of time base correctors, offering features lacking in the current fleet. But more than any one special ability, it was the first-hand endorsement of a trustworthy source: this particular model, a "Component TBC/Transcoder" from the Ontario-based company, was described as a winner when it came to handling the wild and unruly signals of ½'' open reel, BAVC's most frequently transferred video format (introduced in 1965; standardized as EIAJ-1 in 1969).

The DPS-295 would also offer a number of features that could assist with BAVC's second most transferred format, ¾'' U-Matic (introduced and standardized in 1971):

- Y/C 688 Inputs and Outputs (the 7-pin "Dub" connector), relics of the tape-to-tape dubbing days, a high-quality splitting of the luma and chroma channels (1.7V p-p luminance and 0.9V p-p chroma, as opposed to the 1V p-p NTSC composite signal);
- Internal Dropout Compensation (DOC), always a boon for dropout heavy older formats;
- Advanced Sync Output, a composite sync signal (4 V p-p 75 Ohms) sent from the TBC to the VTR, which forces the VTR "to operate at the correct average playback speed"; and
- Subcarrier Output, a color subcarrier feedback signal sent from the TBC to the VTR, potentially reducing chrominance artifacts.[41]

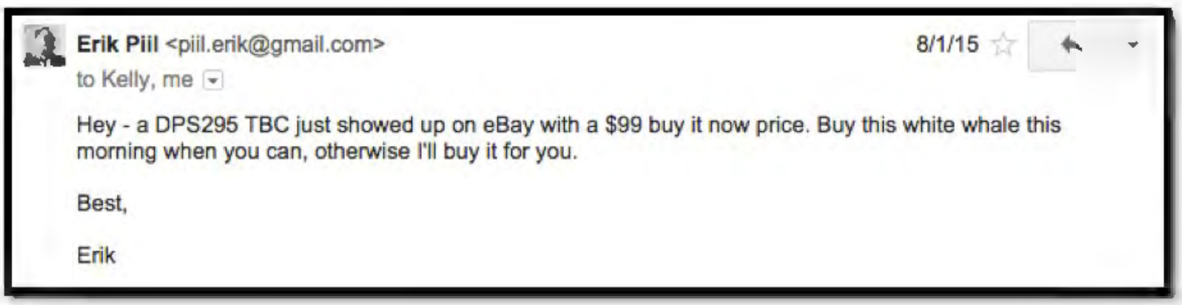
I didn't need to be told twice, especially as I was already something of a TBC enthusiast.

From the very first day that I set foot in the Preservation Suite at BAVC (in May 2014), I was struck by the ways in which the different TBCs and frame synchronizers available to me (at the time: a DPS ES-2200T, a Hotronic AP41, a Sony BVT-800, and an Alta Group Cygnus) were capable of yielding such radically different results. For ½'' open reel in particular, I knew that an external TBC or frame synchronizer was an inescapable part of the equation—these were the only devices capable of bringing the video signal within RS-170A specifications, stabilizing it for further digitization. But still, questions of authenticity and conservation ethics abound. Could the signal processing of one device necessarily be

[41] Digital Processing Systems, "DPS-295 Component TBC/Transcoder Service Manual" (1988).

described as more authentic to the source? What if the choice between two TBCs was not instantly clear, but instead a choice between two different, equally problematic options, say flicker versus a skew error? Was there a right course of action in these cases? Or, better yet: was there an obviously wrong one?

When given the eBay opportunity, I didn't hesitate. Particularly when Erik Piil, MIAP Instructor and Conservation Associate for the New Art Trust and Kramlich Collection, described the ninety-nine dollar, working condition, "Buy Now" DPS-295 as a "white whale," one whose head would rarely pop up in the open auction seas.


Erik Piil <piil.erik@gmail.com> 8/1/15

to Kelly, me

Hey - a DPS295 TBC just showed up on eBay with a $99 buy it now price. Buy this white whale this morning when you can, otherwise I'll buy it for you.

Best,

Erik

Fig. 13 The first appearance of the "white whale"

eBay seller NTC-Tech shipped Item Number 141732874271 almost immediately, and though I had been burned in the past, I still waited with bated breath, hoping for new possibilities and potential, holding on to that hard-to-escape, naïve dream of a "magic bullet" TBC, one that would be capable of resolving any and all problems.[42]

[42] I knew then, as I know even better now, that external TBCs are really only one small part of a much larger equation: the vast majority of playback errors begin and end within the videotape recorder itself. Without first resolving all mechanical issues, any attempt to deal with electronic signal processing (especially that which occurs in a separate machine) is backwards, and will likely be futile. But, there are moments in which a TBC's purpose becomes abundantly clear. For example, a skew or dihedral error can often be traced back to an improperly calibrated record *or* playback VTR; if the error originates at the point of recording, there are two options available: (1) finding a TBC capable of processing the signal correctly; or (2) physically modifying the playback machine to match the improper calibration of the record machine. At times, both of these techniques are required to achieve optimal playback.

Unfortunately, Piil's "white whale" metaphor turned out to be slightly more prophetic than originally expected or intended. While I am not a Melville expert, I can say this: it would be seven months, one thousand dollars, thirty capacitors, four operational amplifiers, one 8-bit A/D convertor, and a bottle of Oloroso sherry later that I would emerge with a fully-functional, better-than-service-manual specifications DPS-295.

The story of how this was achieved will be put on pause, though, as I step back to explore the "magnetic media crisis," the inciting incident (or series of incidents) that sparked my desire to get more involved in the TBC refurbishment process. For, if the crisis is best understood as a series of interrelated events, it calls for a diversity of responses, some of which must include archivists taking up the mantle of equipment repair and maintenance.

"Crisis" and New (Old) Forms of Response

In the race to preserve the world's audiovisual cultural heritage, nearly all roads point back in the same, inevitable direction: in order to achieve its goals, the archival community must turn its attention more fully to the machines that play integral roles in the process of extraction or migration that is digitization.

This is a simple, somewhat obvious sentiment. Yet it is one whose details have been curiously easy to overlook. While one could speculate about why such awareness has never fully blossomed into more widespread action—is it the complexity of playback and peripheral devices; the technical nature of analog video; the history of competition and closed-door thinking among engineers and repair technicians; an archival preference for content over object; or possibly even a church-versus-state mentality governing the archival world (*we* focus on order, organization, and long-term stewardship; *they* focus on machine maintenance and repair)—the result is always the same: if we do not take it upon ourselves to adopt and preserve this distinct set of skills and knowledge, we open ourselves up to failure or compromise.

Even for its most vocal proponents, the "magnetic media crisis"—the prediction of when the combination of degrading tapes and obsolete equipment will make it either impossible or financially prohibitive to transfer magnetic media en mass—is admittedly a form of "crystal ball gazing." [43] Mike Casey, who has galvanized a massive digitization effort at Indiana University Bloomington through this very form of clarion call, described his own chosen dates (2025? 2028?) as hypothetical, as informed by both his own "direct experience with degradation issues in certain formats" and by the experience of vendors who have been "on the front lines of obsolescence…try[ing] to acquire playback equipment to keep their businesses viable."[44] For Casey, regardless of format, all tape-based media exist somewhere on the "downward slope of obsolescence," an eerily predictable sequence of steps that leads from full commercial availability all the way to eBay Russian roulette. In "Why Media Preservation Can't Wait: The Gathering Storm" (2015), he ticks off the stages, one by one:

- End of manufacturing
- End of availability in the commercial marketplace

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[43] Mike Casey, "Why Media Preservation Can't Wait: The Gathering Storm," *IASA Journal* 44 (Jan. 2015): 17. Available on the AVPreserve website at: www.avpreserve.com/wp-content/uploads/2015/04/casey_iasa_journal_44_part3.pdf

[44] Email from Mike Casey to AMIA-L, July 10, 2015. Available at: http://lsv.uky.edu/scripts/wa.exe?A2=ind1507&L=amia-l&F=&S=&P=7084

- End of bench technical expertise
- End of bench technical tools
- End of calibration and alignment tapes
- End of parts and supplies
- End of availability in the used marketplace
- End of playback expertise[45]

Reaction to the crisis hypothesis has run the gamut, from fervent, whole-hearted belief, to nit-picking niggling of the particulars. But the common (and understandable) desire to target the accuracy of the timeline suffers from a misplacement of focus, a failure to understand the crisis on its own terms as largely an advocacy effort. For archivists, it is perhaps best understood as a rhetorical wedge, one designed to spur people (and institutions) to action, to raise awareness in the hope of convincing administrators to invest the resources (human *and* financial) needed to develop comprehensive preservation plans.

But rather than getting bogged down by the chronological calculations of the crisis evangelists, we might instead turn our attention to a different, potentially more problematic aspect of their rhetoric: these thinkers, without question, have favored "massive, rapid digitization" as the best (and largely the only) response to this race against time. While "scaling up" may indeed be the most sensible solution for major holders of audiovisual material (as Casey sums ups: "Small scale, limited solutions may not be of much help"), there are very real dangers associated with understanding our contemporary preservation moment in this way, to fix our

[45] Casey, "Storm," 16.

attention solely on "funding streams," "business cases," and "mobilizing resources."[46] To speak of obsolescence in these terms overlooks a fundamental truth—that obsolescence it is as much a human problem as it is a technological one.

The generation of engineers who specialize in analog video technologies are growing older, retiring, forgetting the knowledge they once had, and, at the very worst, dying. While there are undoubtedly limits to the knowledge they can impart, repair and maintenance training opportunities could increase efficiency, help power better decision making in a critical time, and encourage a younger generation to take part in a community-driven effort to expand and solidify new skills, knowledge, and technique. Instead of waiting for others to determine if our collections are worthy, we must come to recognize that the greatest resource we have is our desire to learn to do this work for ourselves, and subsequently, to teach others to do it for themselves.

In "Quantifying the Need: A Survey of Existing Sound Recording Collections in the United States" (2015), Rebecca Chandler, Chris Lacinak, and Bertram Lyons of the AVPreserve demonstrate both the value—and the starkness—of the more business-minded approach:

> The field is in need of data and research that help quantify the reality of the situation so that we can, with greater clarity and accuracy, demonstrate to funding sources the task at hand and mobilize resources. To that end, we must quantify the needs of audiovisual preservation in business terms.[47]

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[46] Casey, "Storm," 15.
[47] Rebecca Chandler, Chris Lacinak, and Bertram Lyons, "Quantifying the Need: A Survey of Existing Sound Recording Collections in the United States," (2015): 3.

Though useful as a more nuanced form of rallying cry, moving us past the ever-popular “Iceberg Right Ahead!” doomsday scenario, this type of thinking still leaves those most in need—those without the institutional heft to do it themselves, or those lacking the ability to demonstrate “value” to foundational or governmental funding bodies—in a precarious position, unable to save their prized content due to a deficit of practical, cost-effective, do-it-yourself solutions. Instead of minimizing creative in-house approaches, and placing the fates of individuals and smaller institutions into the hands of a rapidly ossifying media preservation vendor oligopoly, we might instead pursue an alternate course, promoting an ideology of self-sufficiency and knowledge sharing.[48]

With the potential to move us past the stale, call-to-arms stage of the crisis, this could be a new, more inclusive way to tackle one facet of this multi-faceted challenge. Taking inspiration from the artists and activists who first embraced analog video, manipulating its newfound potential to suit their own needs, as well as from the free and open source software movements, which have always been motivated by the urge to break apart closed systems, sharing once-closely guarded knowledge freely and widely, by looking to the past we might find a better way of preparing for the future.

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[48] In theory, mass digitization employs a diversity of strategies; in practice, though, it often relies on the work of an increasingly small pool of preservation vendors, many of whom compete over the same core group of projects. In a shrinking industry, consolidation and monopolization are real and acute dangers, and the huge variance in pricing one encounters when soliciting quotes from vendors might be one indication that a few of the major players are driving down prices in an effort to take over the market (which would inevitably lead to prices creeping back up).

All Hands on Deck: Planning and Inspiration

Targeting a particular component of obsolescence—the end of bench technical expertise—my recent efforts to develop VTR and TBC repair skills have been based upon my belief that the advancing age and increasing unavailability of skilled video engineers are far and away the most pressing of obsolescence factors. This concern for people, as well as for legacy equipment and parts, was prompted by the recognition that BAVC's current collection of VTRs and peripheral equipment (TBCs, cleaning machines, etc.) is largely maintained by a single individual: Kenneth Zin, a former Ampex and Memorex video engineer and the principal of Zin VTR Works.

Zin, who spent many of the past years working at the NASA Ames Research Center in Palo Alto, California, repairing Ampex FR-400 tapes drives as part of the Lunar Orbiter Image Recovery Project (LOIRP; http://www.moonviews.com/), recently relocated from the Bay Area to Magalia, California. The now four-hour drive from BAVC's San Francisco facility to Zin's Lab has turned equipment maintenance into a significant logistical challenge, with regular "deck swaps"—trading broken equipment for repaired equipment—occurring at a Sacramento location of the Denny's Restaurant chain. Equidistant between San Francisco and Magalia, Sacramento has proven an unexpectedly ideal meeting ground, offering the opportunity to form closer bonds by catching up and talking shop over Big Slam Breakfasts.

Fig. 14 & 15 Zin at Merlin Engineering Works in 1986; Zin today (Zin VTR Works)

Working for many of the major players in video preservation, Zin's expertise and skills are second-to-none: after serving as a Digital Demultiplex Intercept Systems Repairman in the US Army, Zin spent ten years working for the Memorex Corporation, followed by thirty-five years working as a contractor for Merlin Engineering Works.

Zin's qualifications include training by major VTR manufacturers; throughout the 1970s, he received factory-training certificates from the following:

- IVC (International Video Corporation):
    - 1972 800/700/600 Series Color Video Recorders
- Sony Corporation:
    - 1973 Half-inch EIAJ AV series video recorders with heterodyne color
- Ampex Corporation:
    - 1975 VPR-7950 one inch tape recorder type "A" format
    - 1975 VR-2000 Quadruplex Video Recorder with "Intersync servo"

    - 1977 AVR-1 Quadruplex Video tape recorder with "Buffer" switched delay lines.
- Consolidated Video Systems
    - 1976 Digital Video Signal Corrector (First Digital Time Base Corrector);
- NEC (Nippon Electric Co. Ltd.):
    - 1978 TBC-10/B with Burst control Oscillator[49]

BAVC has been fortunate to have such a resource at its disposal; unlike many video engineers who have been forced into adjacent disciplines (IT, computer systems) as video technologies declined in prominence, Zin has worked continuously in video for nearly fifty years. On a practical level, this means that he has all of the tools, tricks, and sophisticated test equipment needed to ensure the performance of legacy video equipment. But it also means that he has had the time to identify the various components of machines that are most difficult to replace, devising a range of ingenious workarounds and unique custom modifications.

The First Techno-Archaeological Weekend

At the 42nd annual meeting of the American Institute for Conservation of Historic and Artistic Works (AIC, 2014), Michael Angeletti of the Stanford Media Preservation Lab opened his presentation, "Sustaining Playback Through Techno-Archaeology: a VTR Refurbishment Project," with a telling passage from the Videofreex' still-influential *The Spaghetti City Video Manual: A Guide to Use, Maintenance, and Repair* (1973):

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[49] Zin VTR Works, www.zinvtrworks.com/

Og invented the wheel and Sony invented the portable video recorder and something happened in between those two inventions to the way people exchange information that makes this manual necessary. Og had to maintain his wheel in order to use it. And, if Sony technicians were the only people using video, nothing would be different. But what about the rest of us who work with video? Og taught himself how to fix the wheel and passed that information on to other wheel users. Unfortunately, video people can't depend on Sony and the other VTR manufacturers to do the same, at least not in any commonly understandable form. So we're left with Og's original solution—learn to fix it ourselves.[50]

Fig. 16 Og, from the Spaghetti City Manual (Videofreex)

So much is contained in this Neolithic metaphor: the value of open systems and a knowledge-sharing economy; the self-reliance and DIY attitude required in this arena; the challenge of universalizing a deeply technical discourse; and finally, the note of optimistic resignation that should be familiar to most any archivist: "This is what we're left with, so let's make the best of it."

Inspired by Angeletti's effort to add in-house ½" open reel (EIAJ-1) playback to the Stanford Media Preservation Lab by refurbishing a Sony AV-3650 (the black

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[50] Videofreex, *The Spaghetti City Video Manual: A Guide to Use, Maintenance, and Repair* (New York: Prager, 1973): 1

and white EIAJ-1 VTR) with Zin over the course of ten weeks, in the fall of 2015 members of BAVC's Preservation team embarked on a similar mission: we would badger and wheedle our way into an impromptu apprenticeship weekend, documenting the process with a flurry of notes and photographs. Our primary goal was to buttress and expand our skills, gaining a better understanding of the mechanical and electronic inner-workings of a Sony AV-8650 (the color and black and white EIAJ-1 VTR). By having Zin walk us through the process of refurbishing an eBay-acquired AV-8650 of unknown status, we hoped to: (1) improve the quality and efficiency of our day-to-day EIAJ-1 transfers; and (2) take better care of our stable of EIAJ-1 machines, saving resources that could be put to transferring more at-risk video for those in need.

This initial foray into the promise (and potential peril) of learning to repair and refurbish VTRs ourselves, rather than sending machines to a skilled technician at the slightest sign of improper playback, was also designed as a case study: we sought to test what could be learned in a condensed period of time, in hopeful anticipation of larger, more sustainable efforts in the future. Given the good luck of purchasing a machine with a functional video head assembly, we were able to resolve most of the mechanical problems, leaving on Sunday night with a machine ready for incorporation into one of BAVC's digitization systems. The major takeaway of our time with Zin was that much could be learned in a forty-eight hour period, if one has a knowledgeable instructor and the necessary tools and service manuals.

A Second Techno-Archaeological Weekend

Unlike the first weekend trip to Magalia, which was solidly focused on one particular task—refurbishing an AV-8650—a more recent excursion to Magalia (in February 2016) was a ramshackle, smorgasbord-type affair, bouncing from one TBC-related subject to another. Though loose, and devised on the fly, Zin and I still managed to cover a lot of ground, working on three projects:

- To test three Sony BVT-800 TBCs that had fallen out of favor at BAVC (two discovered in a parking garage storage unit, and one that had recently stopped functioning and been removed from preservation operations). Our goals included: (1) determining whether all three units could be repaired; and (2) testing Zin's theory that for ½'' open reel and ¾'' U-Matic, superior transfers could be achieved with a 16-line memory TBC such as the BVT-800, rather than an "infinite window" TBC or a frame synchronizer/TBC unit, which he believed were not as well-equipped to handle the time base errors common in these formats;
- To finish refurbishing and calibrating the "white whale" DPS-295, which Zin had been working on intermittently since the fall of 2015; and
- To compare the signal processing of the refurbished DPS-295 with that of the internal TBC and noise reduction cards of a BVU-950 (the most advanced of Sony's ¾'' U-Matic VTRs, and the only model that offered internal time base correction).

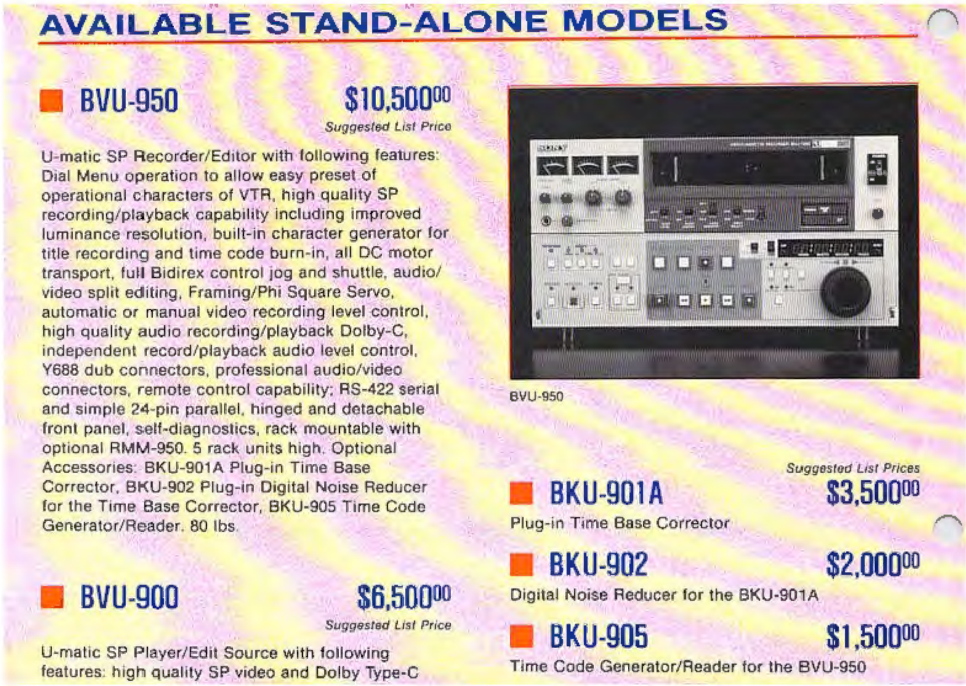

Fig. 17 Sony BVU-950 advertisement, with internal TBC and Noise Reduction card add-ons (https://ear.net/wp-content/uploads/SNY-BVU900-cutsheet1.pdf)

The "Sounds Like a Lawnmower" TBC

We began with the BVT-800s, digital time base correctors introduced by Sony in the early 1980s to complement the 800 series of its BVU line of ¾'' U-Matic VTRs (BVU- 800, 820, 870). Publically unveiled at the 1981 SMPTE technical conference and equipment exhibit at the Century Plaza Hotel in Los Angeles, the BVT-800 was lauded in *BM/E's* January 1982 conference wrap-up, "SMPTE Fall Conference: The Broadcast Perspective":

> A new digital TBC from Sony—The BVT-800—is designed to work in conjunction with the new BVU-800 VCR. Costing in the $10,000 region, it provides viewable pictures up to 40X play speed forward or reverse, plus

> times signals for the dynamic tracking capabilities of the BVU-820. A one line DOC is incorporated."[51]

Contemporaneous advertisements in neighboring issues of BM/E (September 1982, February 1983) again underscore the broadcast origins of Sony's digital time base correctors; under the words "Slow Motion With BVU-820," action-packed images emphasize the brave new journalistic world to be ushered in through portability and advanced signal processing. In one image, a woman can be seen leaping from a helicopter; in another, two policemen are apprehending a fleeing suspect, poised to throw him over a fire hydrant and slam him facedown on the hood of a single-light police cruiser. Below these images, Sony makes its grandiloquent case, informing the reader of "TWO NEW WORDS IN 3/4'' VTRS: DYNAMIC TRACKING":

> Now, for the first time ever, you can make instant broadcast-quality edits of those dramatic events which call for freeze frame, slow motion, fast forward or reverse, without transferring to 1.''[52]

Not only a throwback to an earlier journalistic time, pulling the three Sony BVT-800s out of storage was also a return to an earlier moment in BAVC's own preservation history. Although the machines had been hand-selected by the department's founders for their facility in processing ½'' open reel video, in recent years the BVT-800s had fallen out of favor, replaced largely by infinite window TBCs or TBC/frame synchronizer units (DPS ES-2200T, DPS 290). But in reviewing Luke Hones' "Reel to Real: A Case Study of BAVC's Remastering Model" (2002), a detailing

[51] "SMPTE Fall Conference: The Broadcast Perspective," *Broadcast Management/Engineering* (Jan. 1982): 88-91.
[52] Sony BVU-820 Advertisement, *Broadcast Management Engineering* (Sept. 1982): 153.

of the many considerations that went into designing BAVC's digitization systems, it was clear that earlier generations had favored TBCs with narrower windows of correction. As Hones described:

> The BVT 800 is an older model TBC. This offers an advantage because full-frame TBCs have an inherent flaw when processing weak and unstable video signals. If the full-frame TBC cannot process the video correctly, it strobes the image. Since the BVT-800 is only processing 16 lines at a time, it is more likely to be able to address image problems which a full frame TBC cannot.[53]

In email correspondence, Zin concurred with Hones's assessment, solidifying my hunch that getting at least one of the BVT-800s repaired could be a positive development, potentially improving the quality of BAVC's ½'' open reel transfers. Emphasizing the often-overlooked differences between TBCs and frame synchronizers, Zin explained:

> A TBC has a correction window of between 2 and 32 horizontal lines. A frame sync stores both fields and outputs a frame, but if the deck or tape has dihedral [errors], the frame sync will have problems, such as partial fields from more than one field.[54]

Zin also described something comparable to Hones' "strobing" phenomena, adding, "I've found that when looking at still images on a computer monitor, I see fields of the previous image. Not so with a TBC."[55]

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[53] Luke Hones, ""Reel to Real: A Case Study of BAVC's Remastering Model." Available on The Experimental Television Center website at: www.experimentaltvcenter.org/book/export/html/5782
[54] Email from Ken Zin, Jan. 28, 2016.
[55] Ibid.

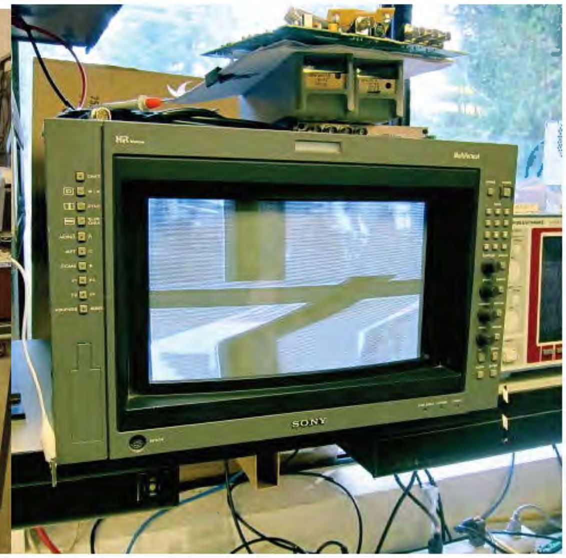


Fig. 18 & 19 Zin testing Sony BVT-800 (L); Skew error visible in monitor's cross pulse mode (R)

Pulling out a tape that exhibited known skew problems (also known as flagging or flagwaving), Zin demonstrated the value of narrower windows of correction, comparing the signal output of the Sony BVT-800s with that of a recently refurbished full frame For.A FA-220 TBC. While the unknown status of the parking garage BVT-800s did lend the test a certain lack of methodological precision, we were impressed with the early results: as Zin (and Hones) had predicted, the 16 horizontal line TBCs seemed better equipped to handle this particular time base error. In "pulse cross" mode (H-V delay), with the horizontal and vertical blanking intervals visible, Zin's monitor clearly showed that a distinct "step error" (the black vertical bar of synchronizing information taking a sharp step to the right in the image above) was better resolved by the BVT-800s.

While the BVT-800 does not offer a "Dub" Y/C 688 input/output, it does have a number of other appealing features, including Advanced Sync and Subcarrier Outputs, and a one horizontal line digital dropout compensator (The "DOC RF" In, designed to be connected to the RF Output of a various ½'' open reel of ¾'' U-Matic VTRs).

2-9-5. Connector Panel

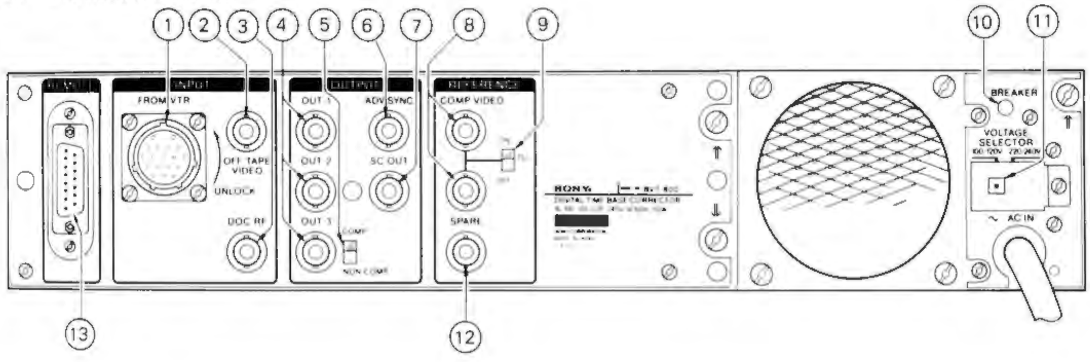


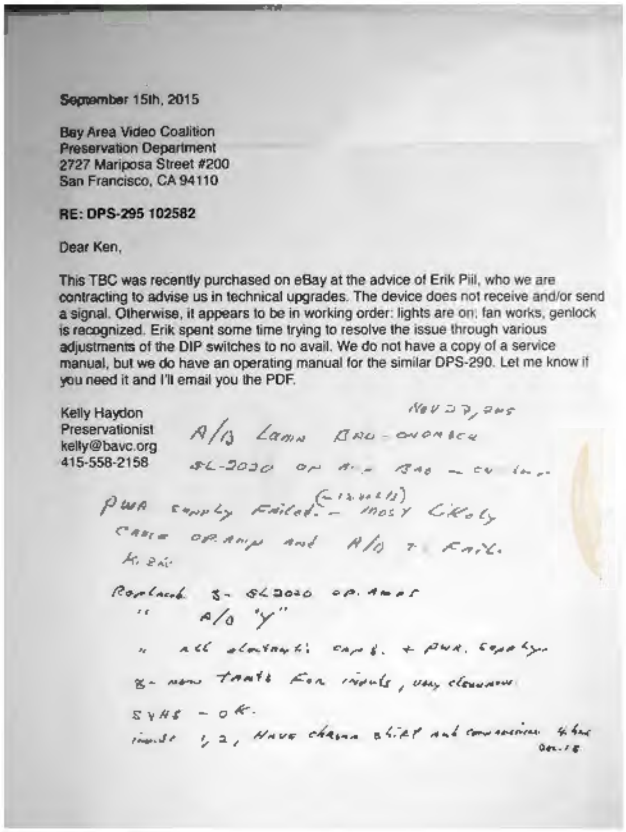
Fig. 20 Sony BVT-800 Connector Panel, with subcarrier out and advanced sync out (Sony BVT-800 Service Manual)

Further testing was put on hold, though, for the BVT-800s all displayed significant problems that would require Zin to special order a number of replacement parts (fans, power supplies, capacitors, control knobs). Zin jokingly described the sputtering fan of one of the TBCs as "sounding like a lawnmower," and any manipulation of the processing amplification controls introduced clear visual disturbances that would be unsuitable for archival use. But despite the need for significant repairs, Zin, in his characteristically terse manner, left me feeling cautiously optimistic, writing in an email: "These units will be very good for the EIAJ and U-Matic decks."

The Return of the White Whale

Having satisfied ourselves with the BVT-800 ½'' open reel test, Zin and I turned our attention to the DPS-295, which, after months of intermittent repair, was still far from ready for incorporation into one of BAVC's digitization stations.

When dropped off with Zin in September of 2015, the DPS-295 was in rough, “as is” eBay condition; a note taped down on the machine detailed the various problems we encountered when testing at BAVC in August.



September 15th, 2015

Bay Area Video Coalition
Preservation Department
2727 Mariposa Street #200
San Francisco, CA 94110

RE: DPS-295 102582

Dear Ken,

This TBC was recently purchased on eBay at the advice of Erik Piil, who we are contracting to advise us in technical upgrades. The device does not receive and/or send a signal. Otherwise, it appears to be in working order: lights are on; fan works, genlock is recognized. Erik spent some time trying to resolve the issue through various adjustments of the DIP switches to no avail. We do not have a copy of a service manual, but we do have an operating manual for the similar DPS-290. Let me know if you need it and I'll email you the PDF.

Kelly Haydon
Preservationist
kelly@bavc.org
415-558-2158

SVHS – OK.

Fig. 21 Letter to Zin, with handwritten notes detailing repairs

Zin’s handwritten notes on the same letter offer some insight into his initial repair efforts, which included replacing one A/D convertor, two EL-2020 operational amplifiers, and a whole host of capacitors (all of the capacitors around the power supply, as well as number of others on the main DPS-295 circuit board, seen below. Nearly all were electrolytic caps that were swapped out for tantalum).

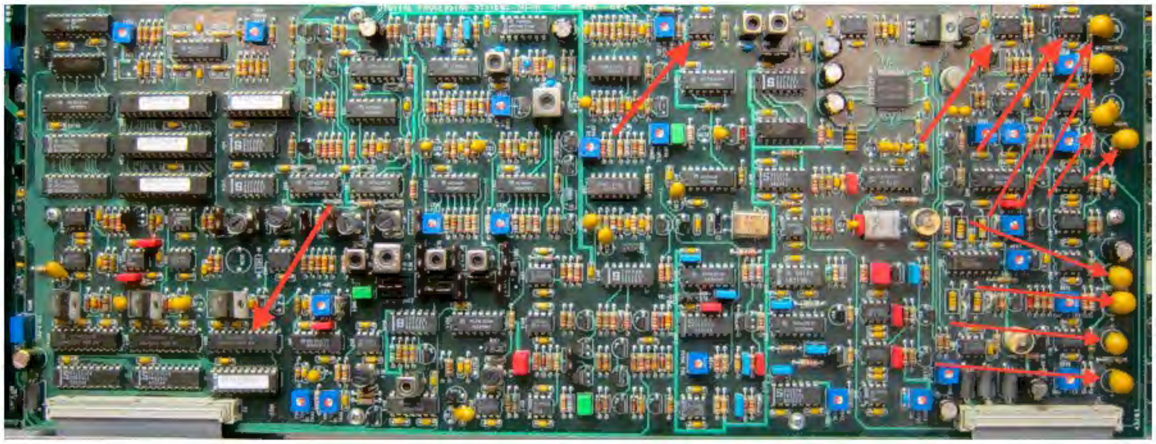


Fig. 22 Main board of DPS-295, with red arrows pointing to replaced capacitors and A-D convertors

Despite Zin's progress, he was hindered by our inability to provide him with one of the key pieces of the repair puzzle: a service manual with much-needed schematics. Service manuals are a continual source of frustration for video engineers; rather than being widely available, manufacturer secrecy and fears of copyright-related litigation have forced many repair technicians to rely on a barter or trade economy, swapping or purchasing manuals only when the need arises.

Over the years, Zin has amassed an impressive array of manuals (four or five massive bookcases packed with thick, heavyset binders), nearly all of which have been painstakingly scanned at high resolution and run through optical character recognition (OCR) software for word-search capability. Yet despite this abundance, Zin's inability to track down a DPS-295 manual highlights some of the central challenges related to service manuals, namely that: (1) availability really varies by manufacturer; for example, the UK-based Snell and Wilcox is notorious for its reluctance to make manuals available in any fashion; and that (2) manuals are not static creatures; service bulletins and add-ons were common occurrences, and often the serial number of a VTR must be cross-checked with three or four different versions of a service manual to ensure compatibility.

Digital Processing Systems, which was founded in 1974 as Digital Video Systems, Inc., suffers from what could called a less acute version of the "Snell and Wilcox Condition;" while service manuals with schematics are, to a certain extent, available, they remain incredibly difficult to track down. An abbreviated, cobbled-together history of DPS includes at least four or five re-brandings or corporate takeovers/buy outs, an all-too-common occurrence that helps explain why TBCs have not received the level of attention they deserve. The simple answer is that these companies are shadows of their former selves, and institutional memory, in large part, no longer exists. While valuable information can be gleaned through persistent pestering (for example, Michael Angeletti of the SMPL was able to locate Steve Denny, a former DPS/Leitch warranty repair technician, by repeatedly calling the Kentucky offices of Imagine Communications), far too often these companies have a vague or unclear sense of their own histories.

DPS History

1975: Founded as Digital Video Systems; pioneers in the development of TBCs and frame synchronizer, and early proponents of 4sc (4 x subcarrier frequency, 14.3 MHz) for sampling video.
1982: Acquired by Scientific Atlanta; focus on satellite encryption technologies
1988: "Studio video product line" spun off, forming employee-owned Digital Processing Systems
1996: DPS goes public
2000: DPS acquired by Leitch
2005: Leitch acquired by Harris Broadcast
2013: Harris Broadcast acquires Imagine Communications; adopts the latter's name[56]

[56] "From TBCs to NLEs," *IBE: International Broadcast Engineer* 318 (Jun. 2001): 36

Thankfully, in the case of the DSP-295, the OldVTRS Yahoo Group came to the rescue; when I sent out a call to the list-serv in November 2015, at least three members emailed back with high-quality PDF scans of the DPS-295 manual. I forwarded them to Zin immediately, but the remaining repairs were saved for my February 2016 visit.

Testing the DPS-295 with a calibrated Tektronix TG 2000 Signal Generation Platform, it was clear that despite Zin's progress, something was still amiss. When sending in a SMPTE color bars test signal (monitored on a Tektronix 1780R Waveform Monitor and Vectorscope), the vectors (Yellow, Cyan, Green, Magenta, Red, and Blue) were all slightly off, not quite hitting their precise markers.

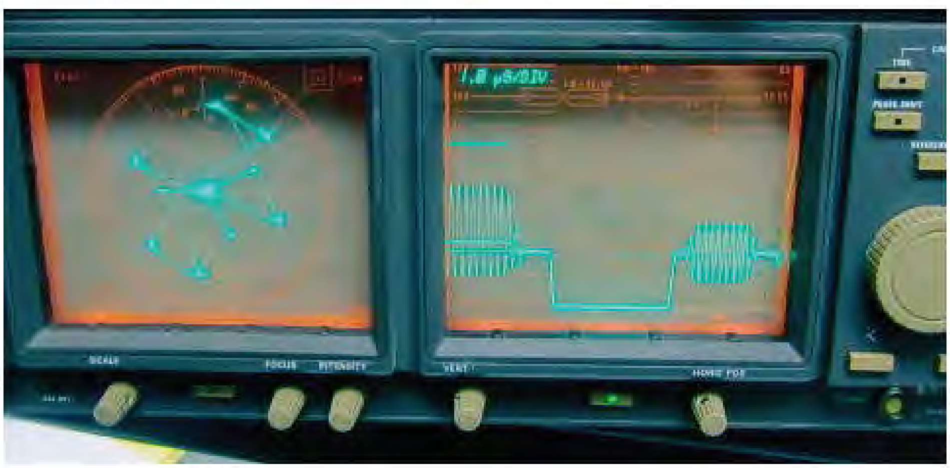


Fig. 23 DPS-295 with vectors slightly off

Somehow—and this was the part of the weekend that I regret not paying closer attention to—Zin was able to review the signal flow diagrams in the service manual schematics to determine that one operational amplifier was the likely source of the problem. We confirmed Zin's suspicion by comparing the service manual alignment specifications with the readings we were receiving on a Keithley 2701 Digital Multimeter and Tektronix 2445A Oscilloscope. Once satisfied, we removed the faulty EL2020 operational amplifier with a solder sucker, then we soldered in a replacement. The improvement was immediate, and to my mind, kind of wondrous: now, when we sent in a SMPTE color bars test signal, the vectors hit their marks perfectly.

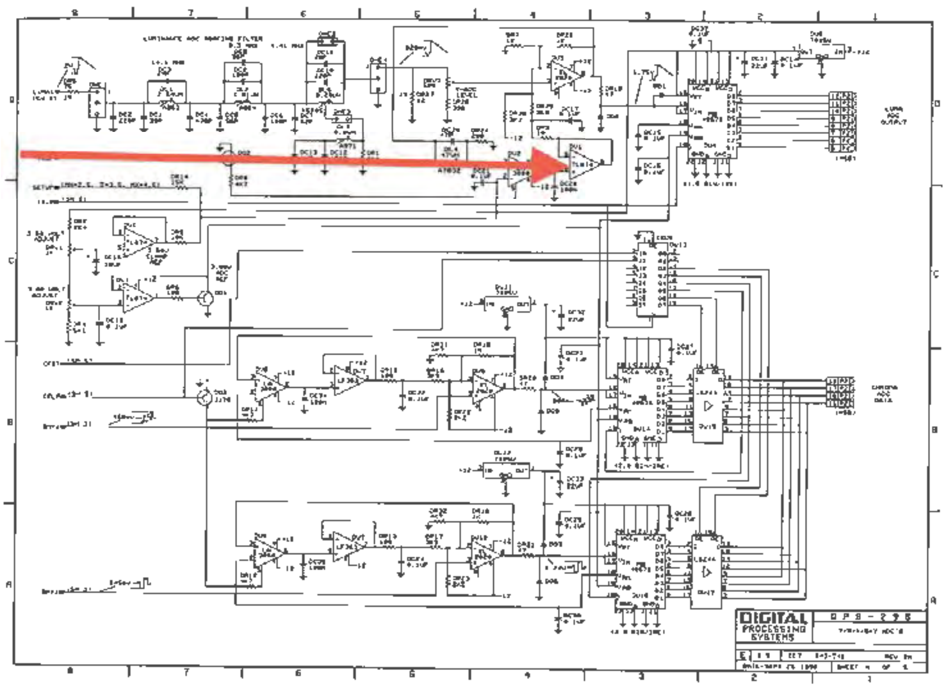


Fig. 24 The culprit—an El-2020 operational amplifier (DPS-295 Service Manual)

Later, we spent a good amount of time running through the rest of the service manual alignment procedures. The process was as follows: different (trustworthy) test signals would be sent into the DPS-295, and minor adjustments would be made to bring the test equipment readings as close to factory specifications as possible. It was easier for two of us to accomplish this work; Zin would move the test probes from one chip to the next, while I would make tiny twisty adjustments to the potentiometers, all while looking closely at the Keithley meter, a precise digital multimeter that offers readings up to the sixth decimal place.

While we were satisfied with the operation of the repaired DPS-295, and pleasantly surprised by some of our test results (for example, better than service manual specification Signal-to-Noise Ratio), further experimentation at BAVC revealed that the TBC is still not quite ready for archival use. Exhibiting an unusual artifact during moments of peak luma (a kind of digital tearing or shearing of the image), it was clear that a future visit to Zin's lab is in order. Though certainly a disappointment, the ongoing malfunctioning of the DPS-295 highlights both the difficulty of repairing TBCs, and the need to thoroughly and critically test all equipment when received from off-site technicians.

Fig. 25 DPS-295 frame-by-frame, with unidentified error corresponding to bright flashes

Internal vs. External Processing

The next day, after we were satisfied (for the moment) with the state of the DPS-295, we turned our attention to a Sony BVU-950 that Zin had recently acquired.

While the BVU-950 is widely regarded as the cream of the crop when it comes to ¾'' U-Matic, it was still illuminating to compare the signal processing of the BVU-950's internal TBC and Noise Reduction cards (the BKU-901A and BKU-902, respectively) with that of the newly serviced DPS-295. Though we did not perform an extensive, methodologically precise test, the internal processing of the BVU-950 was impressive, offering a remarkably clean image with little chrominance noise. Zin also pointed out that to take full advantage of the BVU-950's noise reduction and TBC processing amplification controls, one would need an additional remote unit (a Sony BVR-55).

Fig. 26 & 27 BVU-950 internal NR board (L); BVR-55 TBC for processing amplification (R)

Though internal time base correction is a good default stance for the video preservationist (less components in the signal pathway is generally preferable), this brief cross-comparison again highlights the "case-by-caseness" of this work. Just because one VTR or TBC offers superior processing for one tape does not mean it offer superior processing for all tapes. Understanding how tapes were recorded, and what machines they were recorded on, remains critical. For example, a ¾'' U-Matic tape recorded on a VO-series of Sony VTR may play back better on that than on a BVU series, despite the BVU's much-vaunted "internal processing." And just because, for example, noise reduction is beneficial for one tape does not mean that it will be beneficial for all tapes. David Crosthwait of DCVideo provided insight into his both his methodology *and* guiding philosophy in a 2011 AMIA-L list-serv post:

> The use of the BVU 950 with its internal TBC is about as good as it can get. In my opinion, you probably won't gain anything by acquiring and properly hooking up an external TBC of recent vintage…
>
> We use the BVU 950 in both NTSC and PAL decks with the internal TBCs or external TBCs depending on the situation at hand. Other decks are used also. Occasionally we apply internal or external digital video noise reduction for subjective image improvements. Note that some models of the BVU 950 TBC card have an additional noise reduction capability depending on which version of the card is installed. **But the application of any image improvement method has to be analyzed on a tape-by-tape basis**. Sometimes noise reduction looks better over all, sometimes not. One must use a good quality calibrated monitor (very important!) in a controlled environment to accurately determine image quality while any adjustments are made to the picture.[57]

[57] Email from David Crosthwait to AMIA-L, Oct. 21, 2011. Available at: http://lsv.uky.edu/scripts/wa.exe?A2=ind1110&L=AMIA-L&P=R69524&I=-3&m=40850

IV. Conclusion

This paper has been an effort: (1) to explain what time base correctors are, (2) to provide a brief technological and historical background on these critical components of the process of digitizing analog videotapes (which is essential to preserve an important part of our cultural heritage), and (3) to summarize a personal journey undertaken to learn some of the rudimentary skills required to repair this aging equipment.

In the end, video preservation is about having options, and the time, patience, and know-how to test them in a controlled, structured manner. Moving forward, the obsolescence factors that affect TBCs, and the difficulties (and expense) of procuring them on the open market will only increase in magnitude in the coming years. Just as audiovisual archivists should be familiar with the names, features, and functionality of different TBCs, they should also begin actively preparing for this inevitable decline. Pushing past a dangerous head-in-the-sand mentality, we must begin seeking out the machines, service manuals, tools, and supplies that we will need in the future, and we must actively work to acquire the tricks of the trade while engineers are still available to teach them to us. If we fail in these respects, the burdens of our mission will only become steeper and steeper.