Longitudinal SMPTE Time Code for NTSC Color Video Systems

TIME CODE TUTORIAL

This application note examines and explains the nature of SMPTE Time Code in the professional video and audio fields. This note assumes some basic understanding of time and frequency and the relationship between them, as well as some simple mathematics.

"Real" Time

Although most people think of time in terms of duration, absolute real time can best be thought of as time-of-day.

The world's major timekeeping organizations, including the National Institute of Standards and Technology (NIST, formerly known as the National Bureau of Standards or NBS) and the Naval Observatory (USNO) in the U.S., and the National Research Council (NRC) in Canada, help keep the time-of-day, or Universal Coordinated Time (UTC), consistent throughout the world. Modern cesium and rubidium atomic clocks are capable of maintaining frequencies so stable that it would take more than 350,000 years for an error equal to one second to accumulate.

Although the frequency of these atomic clocks is very precise, our normal measures of time are not perfectly synchronous with the Earth's rotation and revolution around the sun. This is why we require leap years in our calendar. Thus, the actual time-of-day requires periodic adjusting in order to remain synchronous, often done by adding a "leap second" every six or 12 months. Without such corrections, the time-of-day and seasons would slowly drift and, eventually, the sun would be rising at 3:00 in the afternoon and Christmas would seemingly end up in August.

Atomic clocks can independently and locally maintain precise frequency and, therefore, absolute time, but they can only obtain precise time-of-day (UTC) from one of the many standards organizations throughout the world.

In North America there are radio and telephone systems in place which can provide accurate time-of-day to within one millisecond (1/1000th second). Satellite and radio navigation systems can even provide microsecond (1/1,000,000th second) or better accuracy. Since these systems can access precise time-of-day, they are said to be traceable to UTC via the atomic clocks at institutions such as NIST, USNO, and NRC.

Master Clock vs. Master Oscillator

Typically, a broadcast or production facility will maintain a Master Oscillator which is periodically calibrated against one of the traceable standards mentioned previously. The Master Oscillator may be used for the color subcarrier frequency reference in a video facility (typically referred to as a sync generator), or for transmitter alignment to maintain the correct broadcast channel.

Alternately, a Master Clock may be maintained to keep accurate time-of-day for synchronization between facilities, affiliates, and networks. Although a Master Clock may be calibrated to provide a highly stable reference, it is only as precise as the link between itself and the true time-of-day from one of the standards organizations. Manually set Master Clocks are fine for local operations, but synchronization with others requires a link to a true time-of-day reference.

Often a Master Oscillator is mistakenly confused for a Master Clock but, in fact, a Master Oscillator can only maintain a frequency, whereas a Master Clock maintains a true time or time-of-day. (As we shall see later, Master Clocks and Master Oscillators are typically separate and unrelated due to their differing operating frequencies, particularly in video applications.)

Leitch offers both highly stable Master Oscillators (master sync generators) and highly accurate Master Clocks. The Master Clocks contain a telephone modem to allow access to various national standards for time-of-day synchronization.

SMPTE Time Code

To simplify audio and video tape editing, the Society of Motion Picture and Television Engineers (SMPTE) developed a time "code" standard. This time code is basically a digital data encoding method devised originally for use on audio and video tape. "Time Code" will refer to this SMPTE standard in this application note.

Time Code's digital encoding simply applies an "address" to each video frame. This address is also associated with time since it runs

Longitudinal SMPTE Time Code Bit Assignment

START CLOCK EDGE BETWEEN BIT 79 AND BIT 0

Bit	Binary group	Value	Assignment
0		1	FRAMES UNITS
	1st BINARY GROUP	2	
		4	
		8	
4			
8		10	FRAMES TENS
		20	
			DROP FRAME FLAG
			COLOR FRAME FLAG
12		1	DAYS UNITS
	2nd BINARY GROUP	2	
		4	
		8	
16		1	SECONDS UNITS
		2	
		4	
		8	
20		1	MONTHS UNITS
	3rd BINARY GROUP	2	
		4	
		8	
24		10	SECONDS TENS
		20	
		40	
			UNASSIGNED ADDRESS BIT 27
28		1	DAYS TENS
	4th BINARY GROUP	2	
		1	MONTHS TENS
32		1	MINUTES UNITS
		2	
		4	
		8	
36		1	AUXILIARY OFFSET
	5th BINARY GROUP	2	
		4	
40		10	MINUTES TENS
		20	
		40	
			UNASSIGNED ADDRESS BIT 43
44		1	YEARS UNITS
	6th BINARY GROUP	2	
		4	
		8	
48		1	HOURS UNITS
		2	
		4	
		8	
52		8	AUXILIARY OFFSET
	7th BINARY GROUP	16	
		32	
56		10	HOURS TENS
		20	
			UNASSIGNED ADDRESS BIT 58
			UNASSIGNED ADDRESS BIT 59
60		1	YEARS TENS
	8th BINARY GROUP	2	
		4	
		8	
64		0	SYNC WORD
		0	
		1	
		1	
68		1	
		1	
		1	
		1	
72		1	
		1	
		1	
		1	
76		1	
		1	
		0	
79		1	

Date and Auxiliary Offset are encoded and used only by Leitch equipment. The binary group user bits may be used for other functions, depending on the manufacturer from 0 to 29 frames per second, 0 to 59 seconds per minute, 0 to 59 minutes per hour, and 0 to 23 hours per day. Therefore, there are 30x60x60x24 or 2,592,000 unique addresses in every 24-hour day.

The SMPTE standard refers to both a longitudinal track format and a video vertical interval format. The longitudinal Time Code (LTC) is typically used in both video and audio applications, and may be recorded as a standard audio level signal. Transmission is via a two-wire twisted pair. The vertical interval Time Code (VITC) places the data on video lines during the vertical interval. Its transmission, via 75 ohm coaxial cable, is co-incident with the associated video signal. The data is the same for both formats; the transmission medium is the only major difference between the two. All further discussion will refer to the longitudinal format.

Leitch manufactures a versatile line of displays, self-setting analog and digital clocks, up/down timers, and video inserters capable of reading longitudinal SMPTE Time Code.

Fields and Frames

In NTSC video systems, there are 2 fields per complete video picture frame. To simplify matters for now, we will assume we are discussing the old monochrome video rates where there are 60 fields per second or 30 frames per second. True NTSC rates will be discussed later, along with Color Frames and their importance.

Each Time Code address is exactly one video frame in duration. Since there are 30 frames per second, this duration is 0.03333 seconds (33.333 ms), and the associated frequency is 30 Hertz. (Remember, we are still discussing the old monochrome video rates!)

Since the Time Code rate exactly matches the real time rate (60 seconds per minute, etc.), there is no discrepancy between the Time Code address and the actual time-of-day, assuming that the Time Code was properly synchronized with real time-of-day when it was started.

NTSC Color Video

When the NTSC color video system was introduced, a small change was required in order to add the additional color information to the transmission signal. A color subcarrier was added, at 3.579545 MHz, and the signal rates of all other portions of the video signal were then derived from this new subcarrier's frequency. This newly defined relationship changed the horizontal and vertical scanning frequencies slightly. The new horizontal scanning frequency was defined as $\frac{2}{455}$ times the subcarrier or 15,734.26 Hz, while the vertical scanning frequency (field rate) was defined as $\frac{2}{525}$ times the horizontal frequency, or 59.94 Hz. For historical accuracy, the previous horizontal scanning frequency was 15,750 Hz, and the vertical scanning frequency was 60 Hz.

XXIX vs. XXX

One should recognize the change in the vertical or field rate immediately. Previously, it was 60 Hz exactly; however, now it is 59.94 Hz. This may seem like a small amount but, as we shall see later, it adds up quite rapidly. Additionally, the frame rate is only 29.97 Hz or 29.97 frames per second, instead of 30 Hz (30 frames per second). Note, however, that there is still one video frame per unique SMPTE Time Code "address."

So, for tape editing purposes (for which Time Code was originally invented), the new (color) frame rate is fine. This is because the SMPTE Time Code standard defines the Time Code frame duration as equal to the video frame duration, namely, 33.3667 ms ($\frac{1}{29.97}$Hz).

Playback and Program Time

Typically, once a tape has been edited, the total running time or program time must be calculated. If we assume that the tape was re-striped with Time Code starting from 00:00:00.00, then the last Time Code value would indicate the total run time, right? Wrong.

Although the frame rate has changed slightly, the counting sequence of the Time Code has not, simply because there is no easy way to count the fractional value. Some simple calculations illustrate the error. Assuming that the final Time Code value is exactly 1 hour, let's calculate the actual running time. The duration of each video/Time Code frame is 33.3667 ms, and one hour is simply 60 minutes of 60 seconds each, or 3600 seconds. Using the Time Code counting sequence, the total duration is:

$$33.3667^{ms}/_{f} \times 30^{f}/_{s} \times 60^{s}/_{min} \times 60^{min}/_{hr} = 3603.6^{seconds}/_{hour}$$

The actual running time is 3.6 seconds LONGER than the Time Code value indicated!

Drop Frame Fix

Obviously there is a problem, since 3.6 seconds is a considerable error. Basically, as the calculation illustrated, the new frame rate actually adds time when the Time Code value is read as a "time" value rather than the "address" that it properly is.

This problem is easily fixed using a technique called Drop Frame. The fix allows the Time Code address to be read as a time value without the 3.6 second per hour error.

Since the new rate adds extra time, some sort of subtraction is required. If we think of this extra time in terms of extra frames, then we can simply subtract frames to subtract time. The easiest way to subtract during a counting sequence is to simply skip or "drop" a few counts. For example, if you were collecting apples, you could count from 1 to 50 but skip (drop) every count that ended in 5. Although you still counted to 50, you would only end up with 45 apples.

The SMPTE Time Code standard accommodates such a scheme by allowing the first two frames (00 and 01) of every minute to be dropped, except every tenth minute. This amounts to dropping 108 frames per hour:

$2\ ^{f}/_{min} \times 60\ ^{min}/_{hr} = 120$ frames;
except every 10th minute:
$2\ ^{f}/_{min} \times 6\ ^{10ths}/_{hr} = 12$ frames NOT dropped;
therefore:
$120 - 12 = 108$ frames dropped in one hour.
Total time subtracted:
$33.3667\ ^{ms}/_{f} \times 108\ ^{f}/_{hr} = 3.6\ ^{seconds}/_{hour}$

This frame skipping scheme is called Drop Frame, and may be indicated as "SMPTE Drop Frame" or simply "Drop Frame Time Code." It must be designated by setting the Drop Frame Flag, bit 10, in the Time Code data stream.

Editing Revisited

Returning to the edited tape example, if the tape were re-stripped with Drop Frame Time Code starting at 00:00:00.00, then the last Time Code "time" value read would truly indicate the total program run time.

Note that, as far as the video is concerned, there is no difference between Drop Frame and non-Drop Frame, since the frame duration remains the same. Only the counting sequence of the Time Code has been modified in order to bring the "time" value closer to the true time duration of the video.

Coloring the Frames

Our earlier discussion of NTSC color video briefly mentioned the color subcarrier's importance in modern systems. One aspect that should be discussed is the relationship between the subcarrier (SC) and the horizontal (H) video line. This relationship is usually referred to as "SCH," and is discussed in detail in the Leitch Application Note entitled The Modern Systems Approach to SCH and Color Framing in NTSC.

Basically, the SCH relationship is defined by RS-170A. The phase of the subcarrier relative to the horizontal line reverses every line. Since there are an odd number of lines in a frame (525), the phase is reversed at the start of every frame as well.

This phase reversal is the primary reason for the "Color Frame" definition. Simply stated, a "Color Frame" consists of 4 fields or 2 regular frames. Color Field I is that monochrome field on which sync on line 10 is closest to being coincident with the positive-going zero crossing of subcarrier.

Since one "Color Frame" is composed of two regular frames, these two frames are renamed Frame A and Frame B by the SMPTE Time Code specification. Frame A must always correspond to an even-numbered frame number (address) while Frame B must always correspond to an odd-numbered frame number (address). Recall that the Drop Frame process always drops two standard frames at a time, thereby maintaining the correct A/B Color Framing sequence.

Adding further to the SMPTE Time Code specification, the actual Time Code must start during horizontal line 5, which occurs during the vertical interval, of Frame A and Frame B, or Fields I and III of a complete Color Frame. Whenever the Time Code adheres to this Color Framing specification, the Color Frame Flag, bit 11, should be set in the Time Code data stream.

As we shall discuss later, Time Code generators typically adhere to various aspects of the SMPTE specification. Some will generate real time, some Drop Frame, and still others Drop Frame/Color Frame Time Code.

All Leitch displays, analog and digital clocks, up/down timers, and video inserters are capable of reading any type of SMPTE Time Code: real time, Drop Frame, and/or Color Frame.

Holes in the Code

A further feature of the SMPTE Time Code specification is the presence of a number of "empty" bits, referred to as user bits. There are a total of 32 user bits grouped as 8 sections of 4 bits each. These spare data bits may be used to contain a secondary time value or some additional information, such as the date or a time offset. There is no specification for the information which may be placed in these user bits.

The Leitch Master Clock, displays, clocks, and video inserters take advantage of some of these user bits for date and time zone offset information.

Heavy Math

Some of the previous calculations may cause problems for die-hard mathematicians since, for simplicity, these calculations were truncated to only a few significant digits. Using a purist approach illuminates a long-term error associated with Drop Frame Time Code.

To begin with, the original calculations from the color subcarrier frequency are not exact: the vertical field rate is actually 59.94005994006Hz, while the frame rate is really 29.97002997003 Hz. Although seemingly minor, this changes the duration of a video frame from 33.3667ms to 33.36666666667ms.

To see the effects of such a change, let us look at a 24 hour time period:

Normally, there are
$60\ ^{s}/_{min} \times 60\ ^{min}/_{hr} \times 24\ ^{hr}/_{day} = 86400\ ^{s}/_{day}$.
In Drop Frame Time Code, however, there are
$30\ ^{f}/_{s} \times 60\ ^{s}/_{min} \times 60\ ^{min}/_{hr} - 108\ ^{f}/_{hr} = 107{,}892\ ^{f}/_{hr} \times 24\ ^{hr}/_{day} = 2{,}589{,}408\ ^{f}/_{day}$.
Since each frame is now 33.3666666666 ms, then
$2{,}589{,}408\ ^{f}/_{day} \times 33.3666666667\ ^{ms}/_{f} = 86399.9136\ ^{s}/_{day}$,
or $86.400000000\ ^{ms}/_{day}$ short!

Jam Sync and the Hiccups

To the casual observer, a 86.4 ms error seems rather insignificant. However, since one video frame is about 33.36667 ms, this error is actually a little more than 2.26 frames per 24-hour day. After a week, this adds up to more than half a second. After one month, the error is greater than 2 seconds.

This long-term error accumulation is the reason all Drop Frame Time Code generators must be periodically reset to real time if they are to maintain any correlation to the correct time-of-day. Typically, this "reset-to-real-time" is referred to as a "jam sync" procedure. Some jam sync procedures simply reset the Time Code to 00:00:00.00 and, therefore, must occur at midnight; others allow a true re-sync to the correct time-of-day.

One inherent problem with the jam sync correction is the interruption of the Time Code. In order to re-synchronize to a real-time source, the Time Code must stop, re-sync, and the re-start once synchronized. Although this discontinuity may be brief, it may cause Time Code reading equipment to "hiccup" due to the interruption.

Most systems will disregard any Time Code hiccups, since they are primarily non-intelligent readers. However, as more and more intelligent and computer-based systems evolve, the continuity of Time Code will become more critical. Just as you would not reset or interrupt your master sync generator once a day, you would not want to do the same to your master Time Code generator.

Decisions, Decisions!

Having briefly discussed Master Oscillators (sync generators to video people) and Master Clocks, we must now mention Master Time Code Generators.

We have already discussed the differences between Master Oscillators and Master Clocks, but the line between Clocks and Time Code Generators has been undefined until now. A Master Clock maintains accurate real time or time-of-day via a link with a national standard. A Master Time Code Generator simply generates SMPTE Drop Frame locked to video, but may or may not have any relation to the time-of-day. Another primary difference is that Master Clocks maintain accuracy via a highly stable oscillator, whereas Time Code Generators must use the video source as their timebase.

Low-grade Master Time Code Generators only lock to the horizontal and vertical sync signals of the video signal and, therefore, cannot generate correct Color-Framed Time Code. Better Master Time Code Generators will use the color subcarrier as well as horizontal and vertical sync to correctly generate Color-Framed Time Code.

In a truly perfect world all three — Master Oscillator, Clock, and Time Code Generator — could be combined into a single all-in-one unit.

The Pitch: Almost Perfect

Addressing this "perfect" solution, Leitch has developed a Master Oscillator and Master Time Code Generator in one. Additionally, Leitch offers an associated Master Clock.

Using more conventional terminology, Leitch offers a master sync generator and master Time Code generator in a single unit, with room to grow: the SPG-1302N NTSC Sync Generator with the 1302CC Time Code Converter module. Our traditional Master Clock, the CSD-5300 Master Clock System Driver, provides access to stable, reliable, and UTC-traceable real time.

The "Kitchen" Sync

The SPG-1302N provides all the standard sync signals at zero SCH, and may be digitally gen-locked to a more stable video source if necessary. The no-warm-up, high-stability, temperature-controlled crystal oscillator (TCXO) provides the basis for all the signals: sync, blanking, H drive, V drive, Burst Flag, and Color Frame Ident. Additionally, the SPG-1302N provides color black and audio tone outputs, or up to 16 optional 12-bit test signals.

A 2RU model, the SPG-2602N, provides additional "room to grow" for such options as multi-format test signals, electronic stills, source identification, and Time Code keyed onto video.

Hiccup Cures

The 1302CC Time Code Converter occupies a spare slot in the 1300 or 2602 frame, and generates continuous video-locked Drop Frame/Color Frame SMPTE Time Code, as well as a matching RS-232 ASCII time output.

If provided with a real-time source, the 1302CC will automatically perform a once-a-day "soft" jam sync to the real time at a preset hour. The soft jam sync corrects the output Drop Frame Time Code without upsetting the Color Frame reference, the serial data stream, or the Time Code level. No "hiccup" in the Time Code is present, only a "soft" jump in the Time Code addresses. In the worst case, the 1302CC will maintain a continuous Drop Frame/Color Frame Time Code output within 4 frames of the real-time reference.

If a real-time source is not available, the 1302CC can perform a self-correcting soft jam sync once-a-day. The self-correction assumes a perfect subcarrier frequency, and adjusts the output by 2 frames per day. Additional corrections of 4 and 6 frames are performed every 8 days and 192 days, respectively, in order to correct the fractional portion of the long-term error.

A Master for Your Master

To address the Master Clock aspect, Leitch offers the world-renowned CSD-5300 Master Clock System Driver, which is used by many of the world's major timekeeping organizations. The CSD-5300 Master Clock includes an optional telephone modem which allows direct connection to similar units located at timekeeping standards institutions, such as the United States Naval Observatory and the National Research Council in Canada. This modem allows the CSD-5300 to synchronize to true UTC real time via a simple 30-second telephone call. The ovenized oscillator in the CSD-5300 is capable of maintaining correct time with a worst case error of only 3 milliseconds per day.

The CSD-5300 Master Clock outputs SMPTE-compatible longitudinal Time Code, but at the real-time 30 frames⁄second rate without reference to any video signal. The SMPTE specification allows for such a deviation, particularly for audio applications.

The CSD-5300 also provides a RS-232 ASCII time/date serial output; digital BCD serial and parallel outputs; 1, 50, and 60 Hz pulse outputs; 1 and 5 MHz reference outputs; marker beeps; and impulse drive outputs for easy integration into new or existing systems. A 5 or 10 MHz input may be used to reference the CSD-5300 to a more stable cesium or rubidium atomic standard.

All in the Family

In addition to the models mentioned, Leitch offers a variety of Time-Code-related equipment, including digital displays, analog self-setting Time-Code-reading clocks, universal digital clocks, up/down timers, and video insertion devices — all of which can read and display any longitudinal SMPTE Time Code.

Just to whet your appetite:

- DTD-5200 Series Digital Time/Date Displays:
  - Time Code readers
- DAC-5000 Series Digital Analog Clocks:
  - self-setting to Time Code
- ADC-5100 Series Analog Digital Clocks:
  - self-setting to Time Code, or battery-backed
- UDC-5212 Universal Digital Clock:
  - all-LED analog display Time Code reader or clock
- UDT-5700/01 Up/Down Timers:
  - dual-channel timer with Time Code reader, generator, and Time Code calculator
- 1302SI Source Ident module for SPG-1302/2602 Frames:
  - time, date, and text inserter/keyer