**What I've learned about DVD recordings and the WWVB method for synchronizing a local clock which marks seconds on video recordings.**

When I set up my small observatory I chose to record video image data to DVD+R disks. I did this because I didn't have anyone to tell me better and because I also believed that with the recent trends to *digital everything*, brand new VHS-type recording devices were surely destined to become unavailable. The existing recorders will eventually wear out.

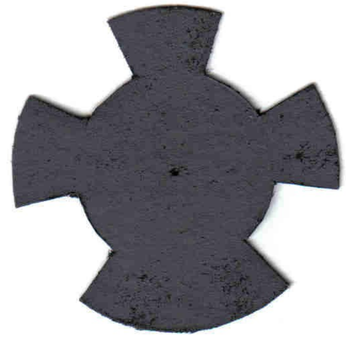
As it turned out, DVD recordings also pose their own special problems. I could put a recorded disk into my desktop or laptop computer and apply any one of a number of programs that rip out a video clip and save it in AVI format, but when I applied Simon Walter's VirtualDub (or any other comparable method for pulling out the two fields of a video frame) the result was serious cross contamination between the two fields. The images are not really separated.

As I learned, cross-contamination of the fields is not a serious problem when my DVD is outputting NTSC to an ordinary RCA TV monitor. Time stamping also reveals the identity of the two fields in a frame. I don't think ViewFields is the problem. The trouble is almost certainly in the DVD ripping process. I'm not into the business of writing a software package for dealing with DVD-sourced video. That left me with the option of using synchronous (or almost synchronous) optical chopping techniques to separate the fields displayed on the TV monitor, and indeed they work, even with a DVD that has not been finalized. A computer is not necessary.

**A device for blinking the two fields in a single video frame, played back from a DVD recording.**

During my career as a chemist I made much use of spectroscopic instruments, e.g., ESR, FT-NMR (including the 2D methods that bring out molecular connectivity), FT-IR, etc., most of which involve Fourier or Hadamard type transforms, so I'm aware that there are various treatments of harmonic data, synchronous or almost synchronous, that allow you to create interesting displays. It turns out that these approaches offer an alternative to ripping and separating the two interlace fields of a video frame without resorting to computer processing of the recorded video images. This approach requires only the DVD recorder, a TV monitor and a couple of optical choppers that spin at an almost synchronous rate.

Lately I've been using a 60 hz, 9-pole synchronous motor from an electric clock, which I outfitted with a special optical chopper wheel, fashioned from cardboard and painted dull black, to blink the two fields of a video frame while you look through it (you just hold the spinning wheel in front of your face and view the TV display through the notches). The chopper has notches for a 30 Hz chopping frequency, which leaves three solid sectors that function at the 30 Hz frequency and one long sector, as shown here:



Since the synchronous motor has nine poles the pole-to-pole rotation would be 360 degrees divided by 9, or 40 degrees. If you cut 40 degree notches (leaving 40 degree solid sectors) the chop frequency is 30 Hz. It doesn't come out even because 9 divided by 2 is 4.5. As the above photo shows, you get four slots of 40 degrees duration and three solid sectors, also of 40 degrees duration; the remainder is a fourth sector of 80 degrees duration. If you had cut 20 degree notches, leaving 20 degree solid sectors, it would come out an even 9 slots and 9 solid sectors, but the chopper would not separate the field images in that case; i.e., you'd just get a 60 Hz chop frequency, which is close to the NTSC field rate and twice the rate of any one video field.

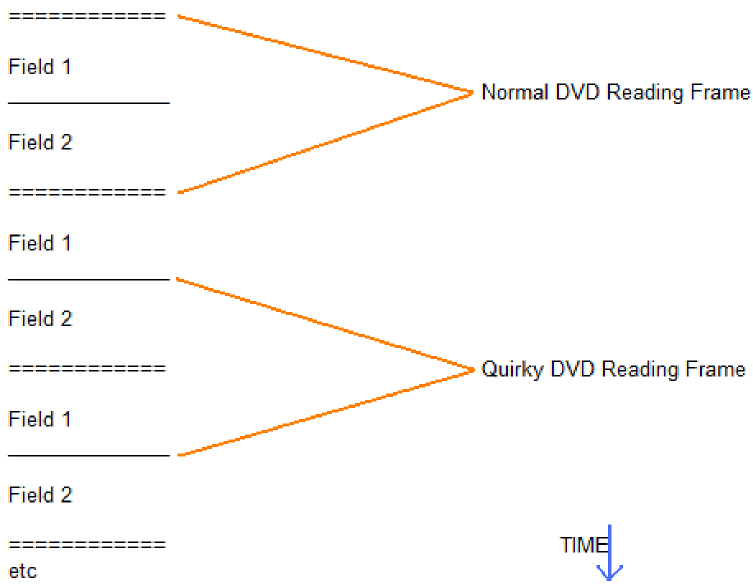
The presence of the longer sector introduces an interesting property: it creates a 180 degree phase shift (for 30 Hz) at every complete turn of the wheel. It is able to separate the two video fields of a played back single frame, so that they alternate in sequence. The essentially static looking image of a displayed single frame thus comes to life (is transformed) as a blink comparator, one that blinks between the two video field images at an easily visible rate.

Obviously, when the DVD is playing back in single frame mode the two fields in that reading frame alternate in sequence for as long as you stay in single frame mode, and that satisfies the NTSC requirements of the monitor. Thus, with the wheel in place and rotating, fields 1 and 2 of a video frame relate, respectively, to the fundamental sine(A) and -sine(A) components of the optical square waves caused by the beam chopping action. If, for example, you freeze one frame from a DVD video recording, one that has been time-stamped by the new IOTA VTI, when you look through the chopper you will see the four digit fractional seconds for fields 1 and 2 blinking back and forth (left and right) at a comfortable rate. Or if you examine the frame where an occulted star was last seen and it is blinking on and off, then the star disappeared (or was attenuated significantly) after field 1. If it is relatively steady - not blinking - It disappeared after field 2. Moving objects blink between the two imaged positions in the traditional blink comparator way, and the chopper wheel could be used that way, too. The separation of fields is distinct for about half of the ~19 second precession time between 60 Hz line frequency and the NTSC vertical frequency. It is very easy to use.

You don't need a computer to do any of this, just the DVD recorder playing back the imagery and the line frequency referenced chopper wheel. My DVD+R is a Magnavox ZC320MW8, and it plays NTSC video to a regular analog TV monitor. When a frame is frozen on the screen and you back step the DVD to the frame preceding it, the image on the screen dwells on just field 1 of the frame you were viewing for about a second, then goes to the preceding frame. It always does that. Forward stepping *sometimes* lets you see field 2, but it isn't reproducible. Actually, the back step provision is all you need; it lets you identify and confirm the specific field where the star disappeared (or had nearly disappeared).

The Magnavox DVD+R does have a quirk. Sometimes the DVD records fields from adjacent frames *as one frame*, e,g., field two from one frame and field one from the following frame, with the pair straddling a frame boundary as shown in the diagram (below). When it does that it is consistent for the entire recording (I have never seen an exception thus far), and if you freeze a frame, in that case, the left hand fractional seconds digits of the IOTA VTI will be a *larger number* than the right hand digits (compare the diagram on the following page with the way the GPS VTI display appears at the bottom of of a displayed single frame, shown further down); if you back step, the field dwell will be on the right hand digits. The back step maneuver thus always displays the first field, time-wise. If the reading frame brackets an even second, that will be evident, too. The DVD+R playback is not ambiguous as long as the imagery has IOTA VTI time stamps, but the recording must include the GPS VTI time stamps somewhere to resolve the way it reads, which certainly affects the WWVB clock's time markers, too. I find myself using a combination of GPS VTI and the seconds stripes from the WWVB-synchronized 1 Hz clock. This recorded reading frame quirk seems to be the exception, not the rule; most of the time the played back fields belong to the same video frame. Sandy Bumgarner suggested a way to turn the GPS time display on and off without consequences.*

As it turns out, this quirk has happened in only two recording so far.  I now have dozens of DVD+R recordings which read normally when you display a single frame, so maybe I accidentally bumped an extra button when I pushed “record” and got a quirky recording.  I don't know what really happened, but at least if it repeats in the future and if the recording also includes GPS VTI time stamps, there will be no ambiguity.   Here is the reading frame diagram:




If the reading frame is normal, this is what a DVD+R playback presents:

P9
 00:17:38 0345 0512 XXXXXX

If the reading frame had straddled a frame boundary you would see something like this:

P9
 02:34:12 0903 0736 YYYYYY  (note that the left-hand fractional seconds is larger)

This quirk is frozen into a DVD recording.  It never changes and apparently always plays back this way.

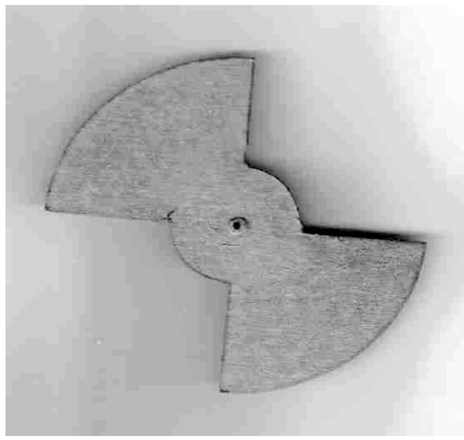
I wouldn't use anything but the GPS VTI for an occultation measurement, but the translucent seconds stripes from my WWVB synchronized clock are less intrusive and more appropriate for lunar meteoroid impact patrols.  I do bring up the GPS VTI display for a couple of seconds, periodically, and I also do the same with video from the camera aimed at the WWVB clock's face, but only at the beginning of the recording.  The latter shows the date, the day of week and the time (hours, minutes and seconds local time), but not the year.  I make sure to mark the year, month and day on the DVD's label.

The DVD recorder does have some quirks, but the GPS VTI  finds them and prevents ambiguity.

As for the WATEC 902H camera that I have, I measured a zero latency using the VTI seconds LED – no accumulation delay.  That, too, certainly affects how you do time measurements.

**An even simpler device for almost freezing a specific field image on the TV monitor**

A simple chopper for separating the two fields of a frame is shown below, and it is driven by an ordinary, geared down DC electric motor. A rheostat between the motor and its power source permits adjusting the chopping rate to ~30 Hz. The rate can be set to precess with the true field frequency so that it dwells on one field for several seconds, then on the other for the same amount of time. That gives you plenty of time to read the GPS VTI time stamp, or to identify which field contains the WWVB clock's seconds stripe.



If an electronic camera is aimed through the rotating chopper wheel it will photograph a specific field, not the whole frame. The camera has to be on a tripod, and the monitor's screen brightness is set a little low, so that several rasters of the field of interest are averaged by the camera. It isn't any harder to do than transferring a DVD to the computer, etc., and you indeed do get just one of the interlace fields that way, whichever one you want. The selected image is then transported from the camera to the computer. For now, that's my way to record a specific field's image, but someone with an inclination to serious computer programming might come up with a ripper that works properly with DVD recorded video. I did manage to find an industrial website and enter my suggestion that DVD players and recorders ought to be able to display each of the two fields, as well as the fields combined as a frame. Field selection would involve blanking the image interval of a specific field but not any sync pulses. That would display the *other* field. It doesn't sound hard to do.

**Evaluating the WWVB-based seconds marking clock**

My first evaluations of this device were presented at the Boston/Cambridge IOTA meting in December of 2010. I used a dual channel oscilloscope to measure the drift rate of seconds strobes from my WWVB-synchronized, crystal controlled 1 Hz clock relative to the leading edge of the even minutes tone from WWV 10 MHz. The clock is a little slow, but this can be compensated by applying a linear predictor equation of the form y = ax + b, as long as the clock's synchronization time is known along with the indicated time of a particular event. Rounded appropriately, “a,” the slope, was found to be 0.0026 s/min (+/- 0.0003 s/min) and the intercept, “b,” was measured at 0.040 s (+/- 0.003 s); the least squares software uses the chi$^2$ method. The slope, “a,” is the drift rate relative to WWV's clock, and it should be constant because it is based on a local crystal-controlled clock in a temperature-controlled environment. As noted, the local clock is slow, so correction times have to be added. The intercept constant “b” is more suspect because it is affected by any jitter in the seconds edges of the demodulated time code (a rectangular wave) coming from the Westclox “Atomic Clock” receiver. Small delays in my own circuitry cannot account for the rather large 0.040 s offset from zero. The observed delay is apparently the consequence of signal filtering/averaging in the Westclox' WWVB (60 kHz) receiver. Thus, the strength of the received WWVB signal ought to affect the intercept, and it does when the signal is weak.

After I received the GPS-based IOTA VTI I used it to re-evaluate my WWVB system. According to the literature that comes with the clock and PDF files available at the website, the GPS VTI reads time at VSYNC, which would be at the bottom of a field image, assuming what is meant is the leading edge of VSYNC. (I'm not quite sure how the developers came up with time stamping that prints the time of a field *before* the bottom edge of that field is reached; perhaps the circuit reads the register, adds 0.0167 s and then prints that value in the *next* field (The alternative would be a breakthrough in time travel!). In doing these measurements I corrected time for the vertical position of the top edge of the broad seconds marking stripe. The vertical width of the image on my RCA monitor is about 8 inches, but I used 9.79 inches to be more exact, because that includes the blanking region of the vertical sync pulse, which, summed with the image, is proportional to a time interval of 0.0167 s. So if I measured a stripe position at, say, 3.00 inches up from the bottom, then the correction factor would be 3.00/9.79 x 0.0167 s = 0.0051 s; the WWVB clock's strobe was *earlier* than the GPS VTI's indicated time by 0.0051 s. Thus, 0.0051 s is subtracted from the VTI's indicated time. All of this may sound outrageously complicated, but it's the kind of thing that spread sheets are meant for. A spreadsheet is also the best way to apply WWVB-based offset and time drift corrections to video data (e.g., occultations, lunar meteoroid impacts, etc.).

My least squares program asks for an estimated probable error, and when - not thinking clearly - I entered 0.1 s for the first GPS calibration data set it came back with this remark:

*"Fit of the form y=ax+b, with a WARNING: The chi-square value from the fit is suspiciously small. If your error estimates are correct, such a value has less than 1 chance in 20 of occurring. Possibly your error estimates are too large."*

Well, yes, and a better starting value might be 0.001 s (which is still too large!). I'm learning to love atomic clocks, both real and proxy, and the little IOTA VTI is a truly wonderful gadget. I went through a lot of data during my career as a chemist, and I've seen many scattered-looking data plots. But here was one where all of the dots were *exactly on a straight line*! Believe me, in chemistry (or biology) that would be cause for much suspicion.

The interface LEDs of my Westclox interface show signal quality rather well. When the RED time code LED is active and the green seconds strobe LED is rhythmic at 1 Hz, without any *extra* strobes between the seconds, then the signal quality is good. Under those conditions, measurements of slope and intercept fell within the the range of the estimated errors determined during earlier measurements using a dual channel oscilloscope (i.e., where drift was measured from the leading edge of the WWV 10 mHz even minutes tone to the leading edge of the seconds strobes coming from the WWVB synchronized local clock).

The GPS based calibration is inherently much more accurate, which is not a surprise. From the clock's measured offset and drift rate using the GPS VTI time standard, "a," averaged 0.00226 s/min (σ = 0.00003 s/min), and the intercept (i.e., the offset), "b," averaged 0.0422 s (σ = 0.0051 s). These mean and standard deviation values came from three separate measurements of the local clock's drift calibration curve (the stated σ-values are based on n-1). The b-deviations are significantly less than the 0.0167 s time interval (1/60$^{th}$ s) of a single video field – resolution achieved by the Westclox WWVB receiver and its local clock synchronizing circuitry is to about 1/200$^{th}$ of a second. The system thus achieves resolution to within one video interlace field standing alone with just the Westclox receiver. On the other hand, if you record the numerical output of the IOTA VTI *plus* the WWVB clock's time stamps (the stripes), you can obtain a drift equation where "b" ~ 0 at the referenced time and "a" is still 0.00226 s/min, accurate to within 1/10,000$^{th}$ second. I believe the seconds-stripes time marking method is much more appropriate for lunar impact monitoring, i.e., it is less intrusive (those numerals at the bottom of the image could hide an impact).

When the signal conditions were questionable, as evidenced by extra strobes on the green seconds LED, “b” became larger, e.g., to as much as 0.062 s, as one might expect for a weaker signal (the leading edge of a seconds edge in the time code would be less steep and cross the detection threshold a little late), but “a” did not change significantly, which is also as one would expect, because it depends only on the characteristics of a crystal-controlled clock. The need for a good WWVB signal is obvious.

I am now building a shielded ten foot loop for WWVB reception, which will use a Ralph Burhans preamplifier. If it will not bring up a good enough daytime WWVB signal, then I'll add an external tuned 60 kHz loop (wound *over* the shielded loop but outside the shield), and I *know* that will do it. The new antenna and its associated monitoring receiver system will have a meaningful signal strength meter. The pre-amplified antenna signal goes to a splitter; one output from the splitter goes to the monitor receiver and the other to the Westclox WWVB receiver. Looks like I'm ending up building a Sudden Ionospheric Disturbance receiver for detecting the x-rays from Solar flares without actually having that goal in mind. I do have a small H-alpha telescope, so maybe I should do more daytime observing.

John R. Wright, submitted November 1, 2011; typo error corrected November 7, 2011

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*Sandy suggested doing this:

“A feature is available in IOTA-VTI that you may find useful. Remove the cover and change the position of DIP switch #3, which is labeled on the PCB as Spare 1, from Off to On (moving it toward the edge of the printed circuit board). That will turn off all character displays while IOTA-VTI is in the Position mode. Time and field count will not be interrupted, so with DIP 3 On you can obtain a record of time and field count using the Time mode, change to Position mode to record your video images, and switch back to Time at the end of your session. It will be necessary to interpolate between the UT time and/or field counts at the start and end to find the time associated with any video feature recorded with IOTA-VTI in the Position mode, but many camcorders and recorders have an internal frame or field counter that will give you accuracy to one frame so you can figure it out.

If you are only operating at your observatory, you may want to leave DIP #3 in the On position, because the most important function of the Position screen is to give geographical position. If, on the other hand, you want to have the Position screen information available from time to time, you can consider accessing DIP #3 by drilling a hole in the cover directly over the six position 'DIP' switch. If your experimenting with that gets a bit out of hand, be assured that replacement covers are readily available.”