Z-100 LifeLine
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Digital Oscilloscope Sampling Rate

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"Z-100 LifeLine"

Update to the DS-138 and DS-150 Digital Oscilloscope Manuals

Oscilloscope Sampling Rate
While working on another project, I needed to check the synchronization signals from the Z-100's Video Logic Board. I used my handy dandy portable DS-150 Oscilloscope (scope), but found some puzzling waveforms during the exercise. It turns out the issue is with the inexpensive DS-150 and similar digital scopes with relatively low sample rates, but I thought that I should let you know of potential issues before you see something similar.

Before I go into the various odd-looking waveforms, let us review what is happening. The following explanation is from the Heathkit Model 4850 Digital Memory Oscilloscope Operation Manual, my other scope. As with all things Heathkit, it makes sense, and might be helpful to you.

Operating Characteristics of a Digital Scope:
This Digital Memory Oscilloscope (DMO) uses digital sampling techniques to represent analog input signals as a series of digital words that are then stored in memory. Since digital sampling systems have disadvantages as well as advantages, it is important that you understand how they operate so you can make the best use of your DMO. This section briefly describes how a digital oscilloscope works and suggests some measurement techniques that will help you avoid the limitations that are inherent in a digital oscilloscope.

Real-Time Sampling
The DMO uses real-time sampling techniques on time base ranges between 20 seconds/division (20 s/div) and 500 microseconds/division (500 us/div). Real-time sampling is a system that, once triggered, takes a series of equally spaced samples of the input signal. One limitation of this type of system is that changes in the signal that occur between samples is lost. This loss of information is referred to as "aliasing."

Aliasing occurs when the input signal is not sampled often enough. This generates false signals that usually appear to be at a lower frequency than the input signal. Unless you know in advance what the input signal looks like, it is usually not obvious that aliasing has occurred. The following simple example shows you how aliasing can occur and suggests a measurement technique to avoid it. If you have a signal generator available, you can perform the following example on your DMO and see the results of aliasing.

Example of aliasing:
Assume a 1000 Hz signal is supplied to the input of the DMO. If you set the time base of the DMO to 1 ms/div, 10 cycles of the sine wave will appear on the display. If the DMO samples the waveform 50 times per division, each cycle of the sine wave is sampled 50 times. The result is a very clear representation of the input signal. See Figure 1.
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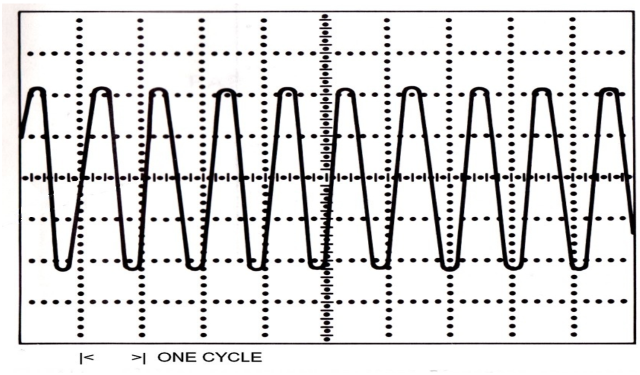


Figure 1a.

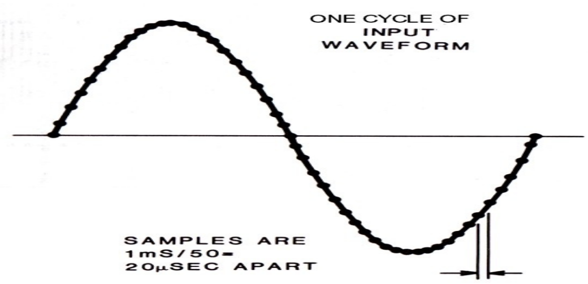


Figure 1b.

Now assume that you change the time base setting to 10 ms/div. The display now looks crowded. See Figure 2.

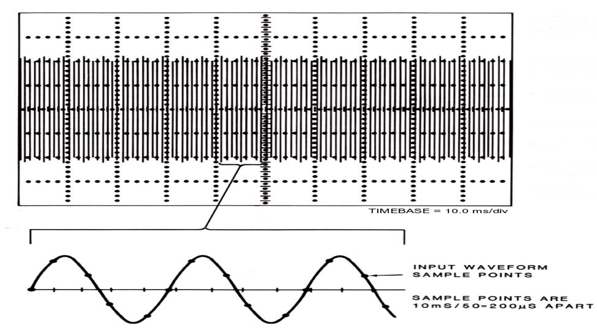


Figure 2.

As mentioned earlier if the DMO samples 50 times per division, it results in sample points that are 200 us apart. Since the input signal is a 1000 Hz (1000 cycles/second) sine wave, it is sampled 5 times per cycle. Although the above display is too crowded to be useful to the eye (it is still useful to a computer), it is not "wrong." Actually, it is much like what you would see on a conventional oscilloscope.

NOTE: If you try this example on your DMO, the display you see will vary due to the exact frequency of the input signal. Vary the input frequency slightly and observe the changes in the display pattern.

Now assume that you change the time base setting to 50 ms/div. The resulting display will most likely resemble the one shown in Figure 3.

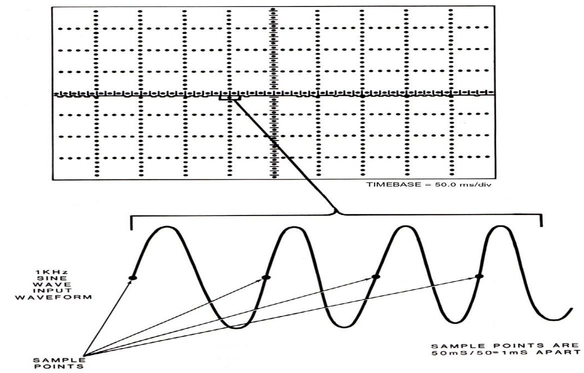


Figure 3.

This is definitely not what you would expect to see on a conventional oscilloscope. To understand what has happened, remember that since 50 samples are taken per division, a sample is being taken every 1 ms. If you draw the original waveform and show the sample points, it would resemble the expanded portion of Figure 3.

As you can see, the input waveform is sampled at the same point each time (assuming the signal is exactly 1000 Hz). Since only the sample points are shown on the display, the display seems to show that the input signal has no AC component, but only a DC component (of zero volts in this example). If you actually try this example on your DMO, vary the frequency slightly and observe the display. You will see various waveforms on the display, but all of them are incorrect. These are all examples of aliasing. Even though the display looks reasonable, the displayed data is incorrect. If you use the measurement technique described next, however, you can always avoid an aliased display.

Measurement Technique to Avoid Aliasing

The input circuits of the DMO have a bandwidth of 50 MHz, but input signals up to 100 MHz reach the digital sampling circuits. A mathematical theorem called the "Sampling Theorem" indicates that aliasing does not occur if the input signal is sampled at least twice per cycle (one cycle at 100 MHz is 10 ns (nanoseconds)). If you wish to sample each cycle at least twice, you must take a sample every 5 ns or faster. If the time base is set to 200 ns/div, a sample is taken every 4 ns and aliasing does not occur for input signals with frequencies less than 100 MHz. This is the key to making alias-free measurements.

If you initially set the time base to 200 ns/div or faster, you can be sure that, even if the display is not useful, at least it will not be aliased. You can now slow down the time base setting until you see a useful display.

Since you have approached the input signal from the non-aliased side, the display is not aliased unless you continue to slow down the time base even further.

OK, so that explains everything, with one note. The inexpensive DS-150 Digital Oscilloscope is limited to a minimum time base of 10 us, not the 10 ns of my Heathkit Oscilloscope. That limits us to about 100 KHz rather than 100 MHz. But for my purposes, that still works.

My experiments are using the Z-100 test bed computer with a standard Video Logic Board, but with the output connectors unloaded; that is, there is nothing connected to the video outputs. The jumpers on the board are set for a standard Zenith RGB CGA monitor using negative vertical and negative horizontal sync.

So, let's look at what my strange waveforms actually looked like.

The synchronization waveforms of the Z-100 Video Logic Board are supposed to look like those of Figure 4.

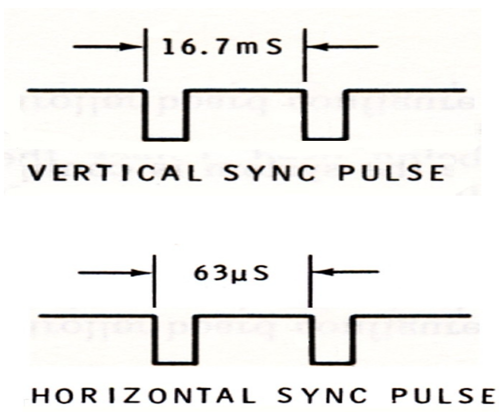


Figure 4. Z-100 Negative Sync

And with a more expensive oscilloscope, they do appear just as they should. However, with the lower sampling rate, my pictures come out less crisp, those of Figure 5. As we are looking for a vertical synchronization frequency of 60 Hz, the wave will have a period of about 16.7 ms, so we set the oscilloscope at the 5 ms timebase.

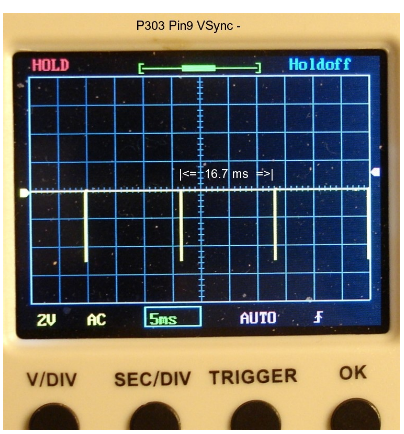


Figure 5a. Negative Vertical Sync

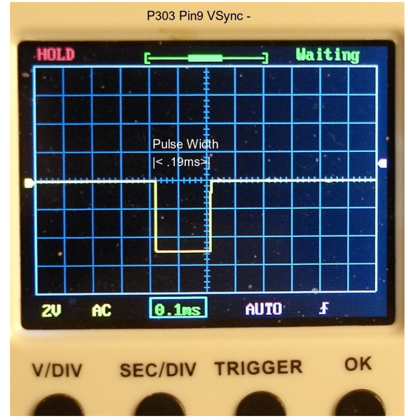


Figure 5b. Negative Vertical Sync Pulse

And at 0.1 ms we see a great square pulse of about 0.19 ms width. But if we increase the timebase we start missing some pulses...

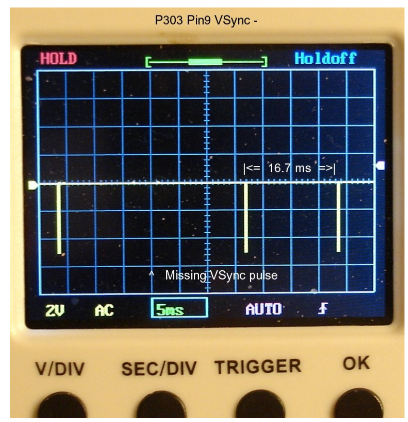


Figure 6a. Negative Vertical Sync

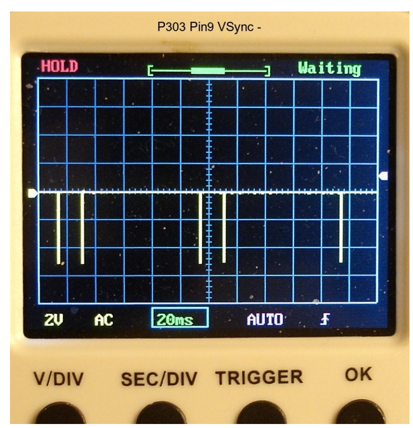


Figure 6b. Negative Vertical Sync

Now let's look at the Horizontal Sync pulses. Since we are looking at a frequency of 15 KHz, the pulse period is about 67 us, and we start on the shortest timebase, as recommended above.

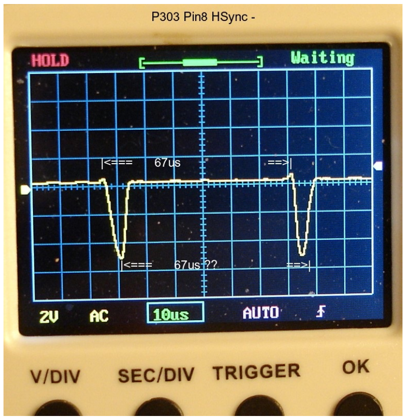


Figure 7a. Negative Horizontal Sync

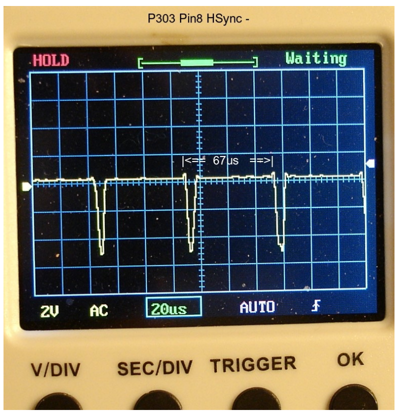
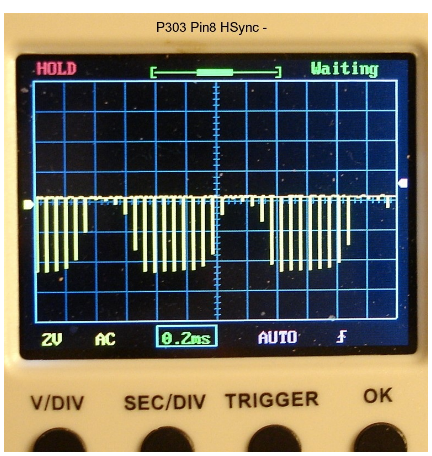
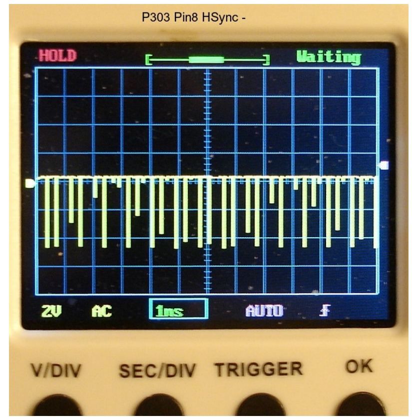


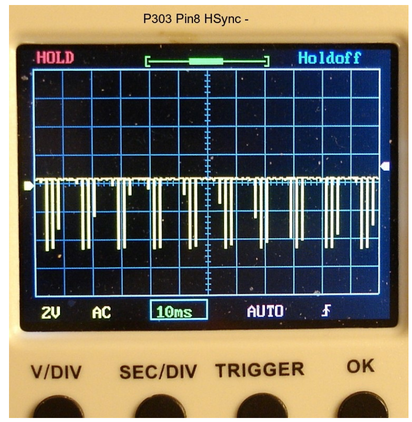
Figure 7b. Negative Horizontal Sync

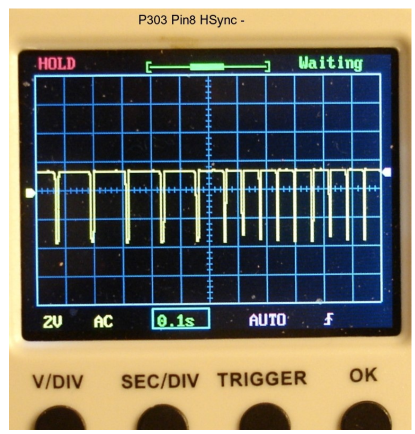
As you can see, the vertical signal pulse looks pretty square, but the best we can get for an horizontal signal on the fastest timebase of our oscilloscope is a rounded negative hump, but the pulse is at the right frequency. On a more expensive oscilloscope with a higher sampling rate, this signal would look normal also.

At the longer timebases, the vertical sync also looks worse, with some of the normal pulses missing entirely at times, but it is the horizontal pulses that are more interesting here. Aliasing at its best. Here are a string of pictures as we continue with longer timebases:









Figures 8. Negative Horizontal Sync

I hope you find this as interesting as I.

If you have any questions or comments, please email me at:
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Cheers,

Steven W. Vagts