Simple Tests for Evaluating Digital Oscilloscopes

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A digital storage oscilloscope is one of the most versatile pieces of test equipment on the market, offering the capability of automatic parameter measurements on a variety of different signals. Individual differences between manufacturers' specifications can make it difficult to evaluate and compare when making a purchase decision. This article shares some simple tests to establish what the DSO's real capabilities are and some quick checks of operational integrity that can be performed before calibration.

The Digital Storage Oscilloscope Simplified

A digital storage oscilloscope (DSO) can measure and display a variety of signals, such as sine, triangle, square or complex waveforms; voltage and timing functions. Triggering functions and automatic features make it possible to capture waveforms and even waveform aberrations not possible before.

In its simplest form, a DSO is comprised of an input amplifier, analog to digital (A/D) converter, computer/microprocessor for timing measurement and a display, as shown in Figure 1.

The waveform or signal to be tested is connected to the DSO's input amplifier. The input amplifier has an attenuate circuit to adjust the amplitude of the signal to the A/D circuits. The A/D circuit converts the analog signal to a digital signal that can be processed by the computer microprocessor of the DSO. The data is displayed on the monitor in a waveform where the vertical axis represents amplitude and the horizontal axis represents time. (Note: this is a simplified description of a DSO.)

All of the tests shown in this article I have developed and adapted over the last 15 years to help in the evaluating and testing of DSOs. These tests can also help in the development of correction factors for better accuracy in the DSO.

For those who are trying to evaluate new or used DSOs, the following tests can be modified to fit your needs. Comparing DSOs can get very confusing with the different operating systems that manufacturers use. Develop a test plan that reflects what you need the DSO to do. Your test plan should include the measurement parameters with the accuracy that you need.

The test plan should include the following:

1. Ground test - checks the level of internal signal noise generated by the DSO.
2. Testing the A/D circuits - checks the A/D for possible bad bits.
3. Memory management of the sample rate - checks how the DSO handles setting the sampling rate in its default or auto setup modes.
4. Bandwidth testing - checks for bandwidth flatness as the frequency increases.
5. Input amp test - checks the vertical amplifier for accuracy and negates the internal random noise of the DSO.

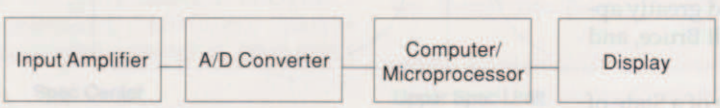

Figure 1. Simplified schematic of a digital storage oscilloscope.

Ground Test

This test checks the level of internal signal noise generated by the DSO. This is important because the noise can become part of the measurement.

Set the DSO up to display a trace. Ground the input of the channel displayed using the DSO's internal ground or an external ground connection. Set the DSO to measure the amplitude of the trace using its own automatic measurement circuits. Adjust the volts per division settings and take measurements throughout the whole range. To average the measurements, convert each reading to a percentage of the volts per division reading then average the percentages. This gives the average of the DSO's random internal noise. The noise will be part of the vertical amplitude measurements at one half a division of

Noise Calculation for 8 Division DSO

1 volt / division noise = 10% (vertical height of display 8 divisions)

1 volt ÷ 10% = 100 millivolts of noise for 8 volts of signal

8 bit DSO = 256 levels or 255 steps of voltage detection (Figure 3)

8 volts ÷ 255 = 31.37 millivolts per level or steps

31.37 millivolts = .392 % of full scale resolution

100 millivolts ÷ 31.37 millivolts = 3.187 or 4 levels or steps of measurement that are internal noise of the DSO.

4 levels ÷ 255 x 100 = 1.568 % of noise for a 1 volt per division setting on the DSO.

Noise Calculation for 10 Division DSO

1 volt / division = 10 % (vertical height of display 10 divisions)

1 volt ÷ 10 % = 100 millivolts of noise for 10 volts of signal

8 bit DSO = 256 levels or 255 steps of voltage detection (Figure 3)

10 volts ÷ 255 = 39.216 millivolts per level or steps

39.216 millivolts = .392% of full scale resolution

100 millivolts ÷ 39.216 millivolts = 2.549 or 3 levels or steps of measurement that are internal noise of the DSO

3 levels ÷ 255 x 100 = 1.176% of noise for a 1 volt per division setting on the DSO.

Figure 2. Noise calculation for 8 and 10 division DSO display.

Number of Bits	Number of Input Quantization levels	Resolution as % of Full Scale
6	63	1.6%
7	127	.8%
8	255	.4 %
9	511	.2 %
10	1023	.1 %
11	2047	.05 %
12	4095	.02 %

Figure 3. Input quantization levels and resolution for DSO bit division.

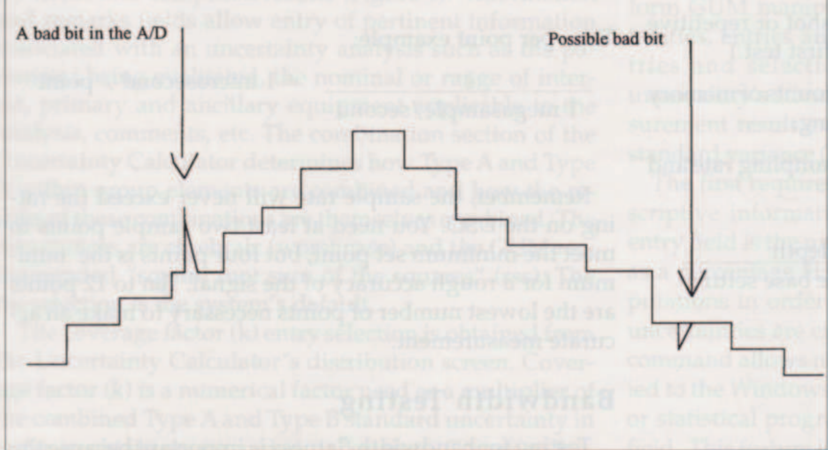

Figure 4. DSO display of 8-bit A/D circuit test.

signal or a full scale signal.

The vertical height of the DSO display needs to be known for computation. This information should be in the equipment manual. Usually it's 8 or 10 divisions for a DSO. Figure 2 shows the noise calculation formula for an 8 and 10 division DSO.

As the example in Figure 2 demonstrates, the noise floor of the DSO can have an important impact on the measurements. By spreading out the display from 8 divisions to 10 for an 8-bit input, the percentage of the noise floor is lowered as the size of the quantization level is increased. This yields a better noise specification, but results in a poorer measurement resolution.

The only way to screen out the noise completely is to average at least 16 signals for the measurement, in effect canceling out the random noise. However, this is usually not practical since DSOs are mainly used in the single shot or nonrepetitive signal measurement mode.

Testing A/D Circuits

If you are evaluating a DSO that has been in use, the A/D circuits should be tested to check the integrity of the A/D converter by showing the quantization levels in the DSO display. An 8-bit A/D will show the vertical and horizontal levels as the waveform is expanded. The display should look like a series of steps going up or down, depending which section of the waveform is examined. (Figure 4.)

As the numbers of bits in the A/D increase from 8 to 12, the size of the steps decrease until at 12 bits the display is a smooth line. This is because the quantization levels are so small, the expansion of the signal is limited by the resolution of the display.

A defective bit will show up as a dot, point or break in the displayed trace at a different level then it should be. This test should always be performed on any DSO to check for damage in the A/D before calibration or performance testing is done.

Connect a triangle waveform of 1 KHz or 10 KHz to an input channel of the DSO (make sure the waveform generator is terminated properly). Set the DSO to display only one cycle of waveform at maximum amplitude on the display without clipping the signal. Save, store, stop or acquire a signal waveform on the DSO. Use the vertical and horizontal waveform expansion controls to expand the waveform to the maximum possible. Scan the waveform to see what the quantization levels of the DSO look like.

Memory Management of the Sample Rate

This test checks how well the DSO handles setting the sampling rate in the default or auto setup modes. The sample rate set by the DSO software is very important to the operation of any testing or waveform analysis. Having the fastest sample rate available is necessary to insure the shortest time between sample points. If the fastest sample rate is 10 nanoseconds per point, any event or signal that occurs between those points is not captured. This makes it very important that the DSO uses the fastest sampling time available. How the DSO's microprocessors sets the sampling rate for the amount of memory used is what needs to be checked.

The memory available for each channel is the main limiting factor of sample rate at the time *per division* settings are made. Therefore, you want to make sure that no matter what memory depth or time base setting is used, the fastest sampling time is available for the measurements.

1. Set the DSO to the fastest time per division and the most memory per channel available.
2. Set the trigger in the auto mode. Set the display to show the sample rate. Set for ether single shot or repetitive mode. Decrease the time per division one setting at a time while observing the sampling rate and the amount of memory used.
3. Repeat step 2 using either the single shot or repetitive mode (whichever wasn't used in the first test.)
4. Repeat steps 2 and 3 using different amounts of memory length or depth for your channel setting.
5. The following formulas calculate the sampling rate and the time per point.

$$\text{Sampling rate} = \frac{\text{Memory depth}}{\text{10 divisions x time base setting}}$$

$$\text{Time per point} = \frac{1}{\text{sampling rate}}$$

dB to % Conversion from 0 Reference Level

dB	%	dB	%	dB	%
3.0	41.3	0.3	3.5	-2.4	-24.1
2.9	39.6	0.2	2.3	-2.5	-25.0
2.8	38.0	0.1	1.2	-2.6	-25.9
2.7	36.5	0.0	0.0	-2.7	-26.7
2.6	34.9	-0.1	-1.1	-2.8	-27.6
2.5	33.4	-0.2	-2.3	-2.9	-28.4
2.4	31.8	-0.3	-3.4	-3.0	-29.2
2.3	30.3	-0.4	-4.5	-3.1	-30.0
2.2	28.2	-0.5	-5.6	-3.2	-30.8
2.1	27.4	-0.6	-6.7	-3.3	-31.6
2.0	25.9	-0.7	-7.7	-3.4	-32.4
1.9	24.5	-0.8	-8.8	-3.5	-33.2
1.8	23.0	-0.9	-9.8	-3.6	-33.9
1.7	21.6	-1.0	-10.9	-3.7	-34.7
1.6	20.2	-1.1	-11.9	-3.8	-35.4
1.5	18.9	-1.2	-12.8	-3.9	-36.2
1.4	17.5	-1.3	-13.9	-4.0	-36.9
1.3	16.1	-1.4	-14.9	-4.1	-37.6
1.2	14.8	-1.5	-15.9	-4.2	-38.3
1.1	13.5	-1.6	-16.8	-4.3	-39.1
1.0	12.2	-1.7	-17.8	-4.4	-39.7
0.9	10.9	-1.8	-18.7	-4.5	-40.4
0.8	9.6	-1.9	-19.7	-4.6	-41.1
0.7	8.4	-2.0	-20.6	-4.7	-41.8
0.6	7.2	-2.1	-21.5	-4.8	-42.5
0.5	5.9	-2.2	-22.4	-4.9	-43.1
0.4	4.7	-2.3	-23.3	-5.0	-43.8

Figure 5. Conversion of decibel to percent of change for bandwidth frequency.

Sample rate example:

$$\frac{\text{10,000 points of memory}}{\text{10 divisions x 1 msec /divisions}} = \text{1 megasample/sec}$$

Time per point example:

$$\frac{1}{\text{1 megasample/second}} = \text{1 microsecond / point}$$

Remember, the sample rate will never exceed the rating on the DSO. You need at least two sample points to meet the minimum set point, but four points is the minimum for a rough accuracy of the signal. Ten to 12 points are the lowest number of points necessary to make an accurate measurement.

Bandwidth Testing

Testing for bandwidth flatness is important because the accuracy of the voltage measurements change as the fre-

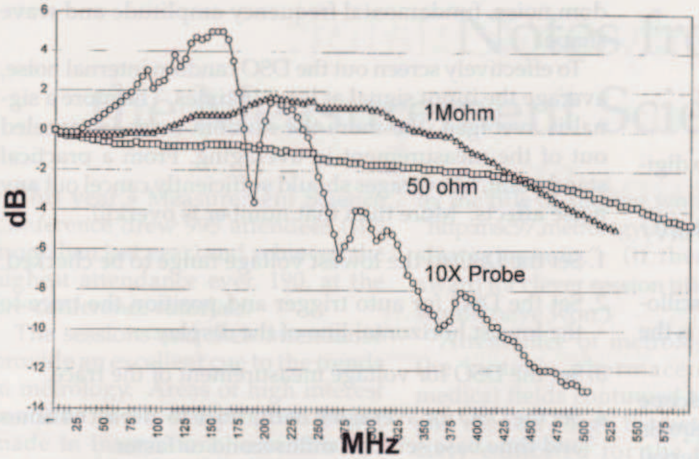

Figure 6. Brand X DSO bandwidth test at 500 MHz.

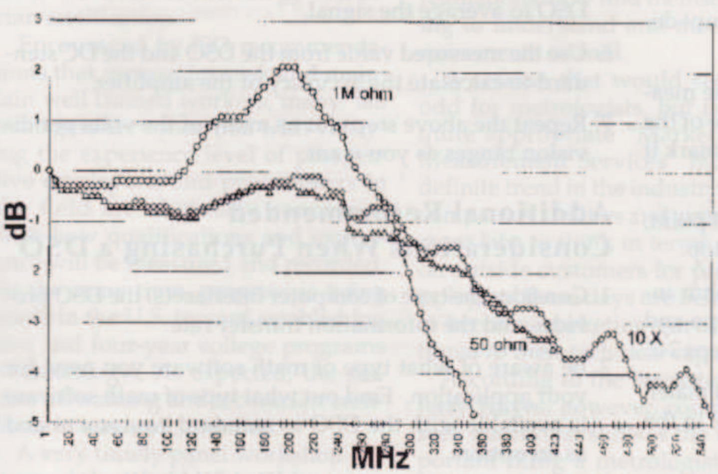

Figure 7. Brand Y bandwidth test at 500 MHz.

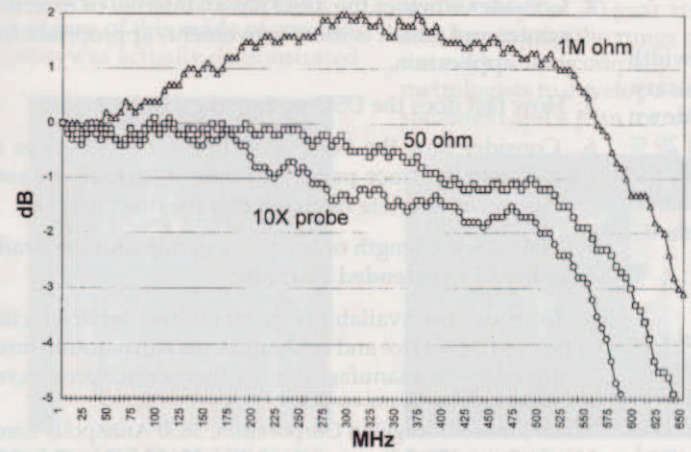

Figure 8. Brand Z bandwidth test at 500 MHz.

quency changes.

DSO bandwidth is one of the most misunderstood specifications, and bandwidth specifications are frequently ignored when making amplitude measurements. The bandwidth is printed on the front of the DSO and virtually every user knows it should not be used for the measurement of signals which have frequencies higher than the listed bandwidth.

What most oscilloscope users forget, is that the bandwidth is a specification of frequency limitation. The specification can be -3 dB down at the specified frequency in reference to a low frequency signal (usually 50 KHz to 3 MHz.) A measurement made at the -3 dB point is a difference (error) of 29% from the reference frequency.

If the measurement is expressed as a percentage of difference from the reference signal rather than simply as a numerical level of dB's, the significance of the difference will be more apparent. Figure 5 is a chart showing the conversion from decibel to percentage of frequency bandwidth.

With the DSO's display of measurement parameters, it is easy to have the DSO make your amplitude measurement for you. This is the point where errors can occur in your measurement. If there is a difference of 1 dB between the reference signal and the signal under test or between two different frequencies this translates to a measurement error of 11%. I personally find this to be unacceptable, and conduct a bandwidth plot of each amplifier under the conditions in which it will be used.

A test plot of three different manufacturer's DSOs using the following test procedure are shown in Figures 6-8. Brand Z shows the best frequency bandwidth pattern with the 10x probe trace pattern closely following the 50 ohm trace pattern.

Oscilloscope Bandwidth Test Procedure

Equipment needed (or equivalent)

- Fluke 6061A RF Generator
- HP Model 11048C with 50-ohm

feed-through termination
- Tektronix coaxial cable 012-0482
- DSO probe to BNC coaxial adapter

Procedure

1. Set the 6061A to 1 MHz, 0 dB output. Connect to digital oscilloscope.
2. Set the digital oscilloscope to 50 ohm input, 100 mV/Div and adjust for best display of signal.
3. Use the measurement functions of the digital oscilloscope to measure the peak to peak voltage. This is the reference level for the rest of the test.
4. Determine the bandwidth of the digital oscilloscope and divide by 100 (bandwidth divided by 100 equals the frequency steps). This is the frequency interval that you use to increase the frequency of the 6061A for the bandwidth testing.
5. Increase the frequency of the 6061A by the amount determined in step 4.
6. Adjust the amplitude of the 6061A to match the measurement taken in Step 3. Record the amplitude of the 6061A. (If you adjusted the 6061A to a +1 dB, mark it on the chart as -1 dB.)
7. Repeat Steps 5 and 6 until you reach the -5 dB point, or whatever frequency at which you wish to stop.
8. Reconfigure the digital oscilloscope for 1 Mohm input. Attach the 50 ohm load to the oscilloscope and connect the 6061A to the 50 ohm load. Repeat steps 2-7.
9. Connect the scope probe to the oscilloscope and match the probe to the oscilloscope per the procedure in the operator's manual.
10. Connect the 50 ohm load to the 6061A. Connect the BNC to the scope probe adapter to the 50 ohm load. Connect the scope probe to the adapter. Repeat steps 2-7.

The above procedure is used to generate the bandwidth plots in Figures 6-8 and may be modified as necessary. Remember, the bandwidth specification is -3 dB down from the reference frequency. This is a difference of 29 % and with the DSO still in specification. As shown in the bandwidth plots, even at frequency of 10% of the bandwidth, errors of 1 to 3 % are possible in the measurements.

Input Amp Test

An accuracy check on the input amplifier should be performed. This test checks the vertical amplifier for accuracy while screening out internal random noise. The test works best with DC voltage input because any jitter in the trigger circuit is avoided. If an AC signal is used, any existing trigger jitter will be averaged into the random noise, fundamental frequency amplitude and wave shape.

To effectively screen out the DSO random internal noise, average the input signal at least 16 times. The more a signal is averaged, the more the random noise is canceled out of the measurement in averaging. From a practical stand point, 64 averages should sufficiently cancel out any noise affects. More than that number is overkill.

1. Set the DSO to the lowest voltage range to be checked.
2. Set the DSO for auto trigger and position the trace to the lowest horizontal line of the display.
3. Set the DSO for voltage measurement of the trace.
4. Set the DSO for averaging of the trace to at least 64 times and time base set for 1 millisecond or faster.
5. Input a DC signal of at least 7 divisions vertical amplitude (voltage standard or monitored source) and set the DSO to average the signal.
6. Use the measured value from the DSO and the DC standard to calculate the accuracy of the amplifier.
7. Repeat the above steps for as many of the volts per division ranges as you want.

Additional Recommended Considerations When Purchasing a DSO

1. Consider the type of computer interface(s) the DSO provides and the information transfer rate.
2. Be aware of what type of math software you need for your application. Find out what type of math software is available with the DSO as standard equipment and as an option.
3. Consider the resolution of the video display and whether there are other display devises.
4. Consider whether the DSO has an internal or external printer and which is more convenient/appropriate for your application.
5. How fast does the DSO update the display?
6. Consider how the DSO saves the trace file. Does it save only the trace pattern or does it include the settings for a complete re-creation of the display?
7. Consider the length of warranty period and the availability of an extended warranty.
8. Consider the availability of repair and service facilities, cost of service and calibration, and turnaround time offered by the manufacturer or other service providers.

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