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# Procedure to Determine the Two Channel Timing Measurement Accuracy and Precision of a Digital Oscilloscope

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## Disclaimer

# Procedure to Determine the Two Channel Timing Measurement Accuracy and Precision of a Digital Oscilloscope

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The digital oscilloscope allows one to make numerous timing measurements, but just how good are those measurements? This document describes a procedure which can be used to determine the accuracy and precision to which a digital oscilloscope can make various two channel timing measurements.

**Theory.**
Let the oscilloscope make a measurement of the difference in time of arrival of a signal in one channel and the same signal delayed by a variable delay line in a second channel. Change the delay and repeat the measurement. Continue to make the measurement for various values of delay, then perform a linear regression on the obtained data points. The precision of the timing measurement of the oscilloscope, to one standard error, will be no greater than the standard error obtained from fitting a linear equation to the set of measured values. The time base accuracy of the measurement can be gauged by comparing the computed slope of the fitted line to the inverse of the velocity of propagation through the delay line.

**Implementation.**
The general setup for the procedure is shown in Figure 1. This set up can be modified for specific measurements.

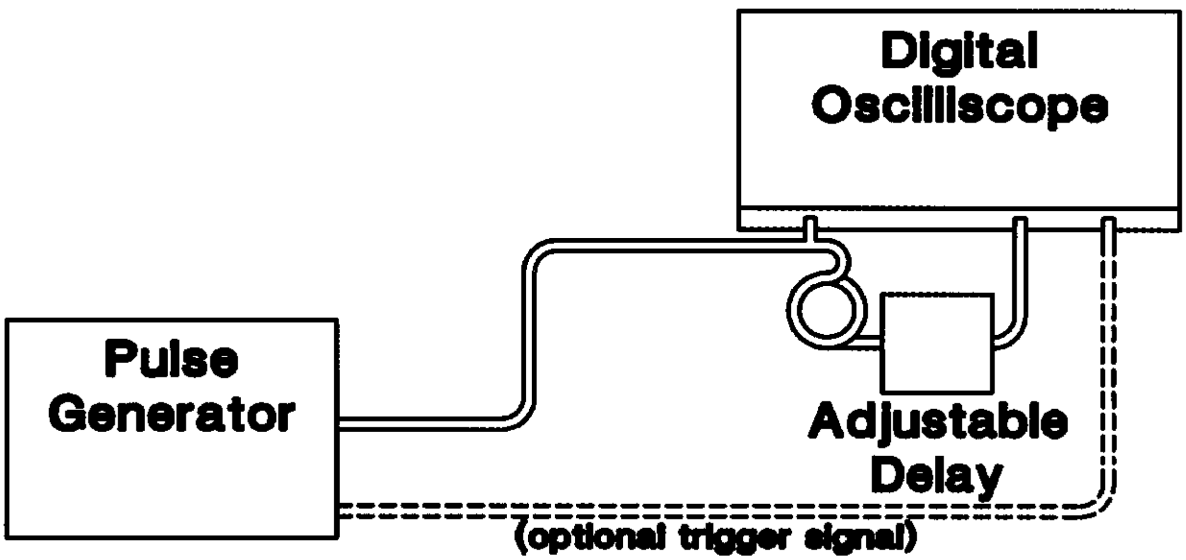


**Figure 1.** General setup for determining Digital Oscilloscope Precision

The adjustable delay is an air core adjustable delay line. The air core adjustable delay line is constructed as two rigid coaxial transmission lines which can slide over one another creating one variable length coaxial transmission line, somewhat resembling a trombone. The adjustable delay line has BNC connectors at either end and a characteristic impedance of 50Ω making easy and well matched connections to RG58 cable. Using a scale, the length of the delay line (and in turn the value of delay) can be set in regular and repeatable intervals.

The air core adjustable delay line which we used had a delay range of about 1 ns. to 2 ns., with an overall length of about 1 foot when closed and an overall length of about 2 feet when fully extended. We made 5 measurements at each of 10 equally spaced locations over the length of the delay line.

**Slope and Standard Error Calculation.**
This procedure generates a series of data points of the form ($x_i$, $y_i$) where $x_i$ is the set of adjustable delay line positions (in mm.) and $y_i$ is the set of measured delay values (in ns.). This set of data points was entered in to an Excel spread sheet, where the linear regression parameters were computed. A scatter plot of the actual data points, superimposed with the computed line were plotted to visually inspect the fit of the line.

Given the set of data points ($x_i$,$y_i$), the slope (m) and y-intercept (b) can be computed as:

$$m = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{n\sum x_i^2 - (\sum x_i)^2} \qquad b = \frac{\sum y_i - m\sum x_i}{n}$$

The standard error of the data points to the fitted line is computed as:

$$\sigma_{y/x} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - (mx_i + b))^2}{n - 2}}$$

**Observations and Results.**
Based on the computed slope of two fitted lines for measurements made with an oscilloscope that had just returned from a National Institute of Standards and Technology (N.I.S.T.) traceable calibration, the propagation delay for the air core variable delay line was found to vary by 0.003428 ns/mm, corresponding to a propagation velocity of 0.973c. The accuracy to which the length of the adjustable delay line can be set is estimated to be ±0.25 mm. This would indicate that the timing measurements would have an error of no more than ±0.86 ps. due to delay line positioning. As this setup produces a relative timing measurement, it should be immune from jitter in the pulse generator.

We performed this measurement on several of the digital oscilloscopes which we use, and found the precision to be quite good when the scope was allowed to average or sample the wave forms many times before making the measurement. The worst case result for this mode of operation was a standard error of 10 ps. Much worse was the 101 ps. standard error for measurements made when one of the oscilloscopes ran in "real time" mode. In all cases, greater precision was obtained by allowing the oscilloscope to sample or average more events before making the measurement. The cost of the higher precision was the time spent waiting for the measurement.

The accuracy of a given measurement can be gauged by comparing the slope of the computed line to the 0.003428 ns/mm constant determined for the delay line. Dividing the difference of the computed slope and the delay line constant by the delay line constant, one can establish a percentage of variation in accuracy. When examining the accuracy of the various measurements, we found a broad range of accuracy variation. In the worst case, the measurement made with "real time" acquisition computed a slope which varied by more than 10% from the delay line standard. Indeed, the measurement which was made with the most precision was one of the most inaccurate. Note, that accuracy is a dynamic variable, probably deteriorating over time, but periodic recalibration of the oscilloscope should help reduce the variation in accuracy.

Table I tabulates the results of the measurements taken to date.

**Table I** Results of two channel timing measurements.

| Oscilloscope and measurement description | Standard error (ns) | Computed slope (ns/mm) | % of accuracy variation |
|---|---|---|---|
| Hewlett Packard HP54100D | | | |
| 1ns/div. 32 averages | 0.009 | 0.003418 | -0.28 |
| 1ns/div. 8 averages | 0.010 | 0.003437 | +0.28 |
| Hewlett Packard HP54111D | | | |
| 1ns/div. 32 averages | 0.005 | 0.003370 | -1.68 |
| 1ns/div. 0 averages | 0.016 | 0.003380 | -1.39 |
| 5ns/div. 32 averages | 0.005 | 0.003378 | -1.44 |
| 5ns/div. delayed 2μs from trigger 32 averages | 0.020 | 0.003384 | -1.27 |
| 1ns/div. real time acquisition | 0.101 | 0.003785 | +10.4 |
| Tektronix DSA602A | | | |
| Main to Window Trigger 1000 averages | 0.004 | 0.003344 | -2.44 |
| Prop. Delay 1000 samples | 0.010 | 0.003382 | -1.33 |
| Prop. Delay 32 averages 1000 samples | 0.007 | 0.003388 | -1.15 |
| Prop. Delay 5000 samples | 0.005 | 0.003398 | -0.86 |
| Cross Measurement 1000 samples | 0.004 | 0.003358 | -2.03 |
| Cross Measurement 5000 samples | 0.002 | 0.003272 | -4.54 |
| Tektronix TDS644A | | | |
| Delay 32 averages | 0.003 | 0.003343 | -2.47 |
| Delay 8 averages | 0.005 | 0.003320 | -3.14 |
| Delay 0 averages | 0.015 | 0.003305 | -3.57 |

Table II tabulates the data obtained for one of the oscilloscope measurements which we tested.

**Table II** Oscilloscope measurement data.

| Delay line position (mm.) | measured delay (ns.) | | | | |
|---|---|---|---|---|---|
| 10 | 7.51 | 7.51 | 7.52 | 7.50 | 7.52 |
| 35 | 7.59 | 7.59 | 7.60 | 7.59 | 7.60 |
| 60 | 7.70 | 7.71 | 7.70 | 7.69 | 7.70 |
| 85 | 7.79 | 7.80 | 7.80 | 7.79 | 7.79 |
| 110 | 7.87 | 7.87 | 7.87 | 7.88 | 7.88 |
| 135 | 7.95 | 7.95 | 7.96 | 7.95 | 7.96 |
| 160 | 8.04 | 8.04 | 8.03 | 8.04 | 8.04 |
| 185 | 8.12 | 8.12 | 8.12 | 8.13 | 8.12 |
| 210 | 8.21 | 8.20 | 8.19 | 8.20 | 8.22 |
| 235 | 8.29 | 8.29 | 8.29 | 8.29 | 8.28 |

Performing a linear regression on these points results in a line with a slope of 0.003437 ns/mm and a y-intercept of 7.487 ns. with a standard error of 0.010 ns. Following is a scatter plot of the data points with the computed line superimposed.

**HP54100D (1ns/div 8 averages)**

Standard error =0.010ns