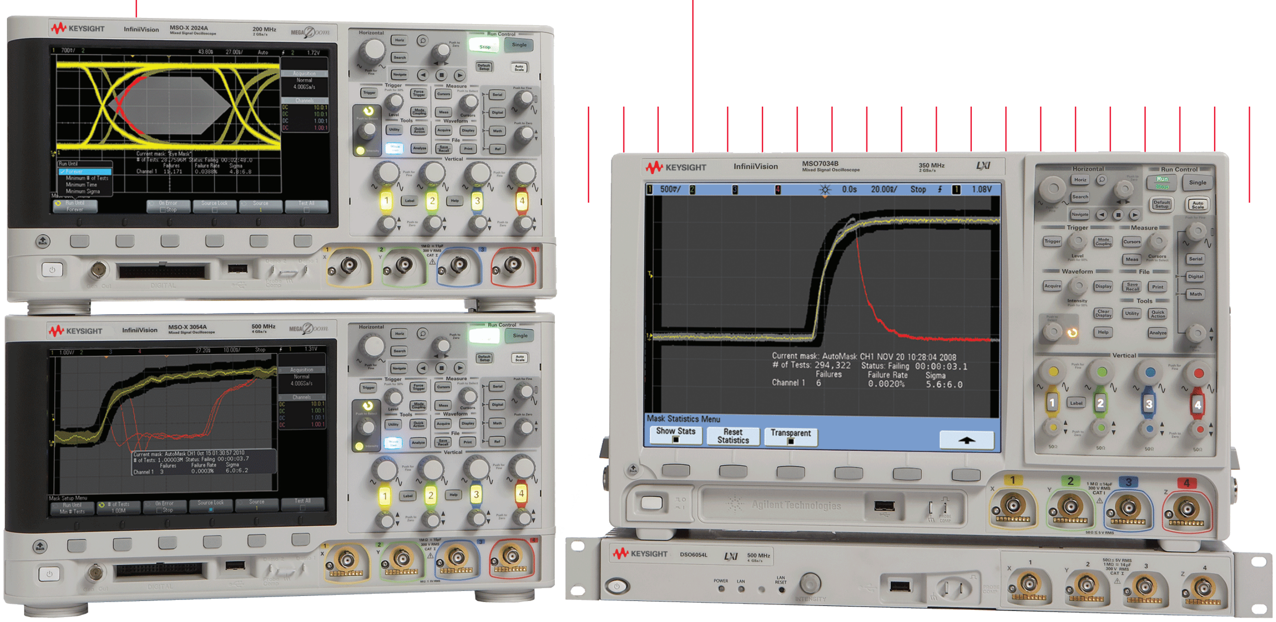
Keysight Technologies
Evaluating Oscilloscope Mask Testing for Six Sigma Quality Standards

Application Note



KEYSIGHT
TECHNOLOGIES

Introduction

Engineers use oscilloscopes to measure and evaluate a variety of signals from a range of sources. Oscilloscopes play a major role in both design and manufacturing—presenting an engineer with a visual display of voltage over time. It is crucial to have an oscilloscope that will not only provide accurate visual representations of the signal, but will also provide usability and functions that makes designing and testing signals easier.

Every manufacturer must address quality assurance (QA) to ensure products consistently meet standards for design and performance and maintain a low defect rate. QA is a systematic approach to designing and providing processes to ensure confidence in and sustainability of a product's quality. As part of the QA process, you must test and verify product operation many times at each stage in design and validation. For products that generate electronic signals such as integrated chips (ICs) and field programmable logic arrays (FPGAs), you must verify that each signal operates within required tolerances for signal integrity. These tolerances, measured with an oscilloscope, include various signal attributes such as peak-to-peak voltage, frequency, RMS voltage, and delay.

The ideal QA process for products that use electronic signals would test signals for high quality standards (low failure rates) utilizing a large number of samples, without impacting test times. Such a QA process would yield three key benefits: 1) high quality products in less time, speeding up time to market, 2) greater customer satisfaction, and 3) allow designers and engineers to spend more time creating new designs rather than fixing old ones.

This application note discusses the statistical principles that apply to the QA process and the evolution of Six Sigma efficiency–defined as achieving a defect rate of 3.4 per million or less. We will then explore the benefits that mask testing brings to the QA process for electronic signals and its use to achieve Six Sigma quality in as little as 1.1 seconds.

Gaussian theory

To use QA processes effectively we first need to understand statistical theory and the role it plays in modeling a process. QA is not only concerned about testing and validating a product's performance; it is a methodical way of developing techniques that increase the probability your product will function as specified. The best way to verify functionality is to make many observations of your product's characteristics and see how these characteristics vary from unit to unit. To do this, you need to measure the critical characteristics and build a database or histogram of your results.

Building a statistical database begins with taking many samples of a specific measurement. For example, we could measure the shell diameter of a specific species of turtle to the nearest millimeter and then plot the shell sizes (x-axis) against the number of occurrences of that shell size (y-axis). We would find that certain shell sizes occur more frequently than others. We would also find that as we plot the diagrams of more and more turtle shells, the histogram takes on a curved shape, as shown in Figure 1.

The plot may take on a variety of shapes depending on whether each sample is independent of the next. To simplify and broaden the application of this example, however, assume that each sample is independent and randomly chosen (in other words, an independent random variable). If these two requirements hold true, the plot will form a curve shaped like a bell (see Figure 1). This bell curve is known as a Gaussian (or normal) distribution. Gaussian distributions are important in the study of statistical probabilities and are commonly observed in nature. The thicknesses of zebra stripes, the height of pine trees, and the height of humans are all naturally influenced measurements that result in Gaussian distributions. The same can be said of the characteristic and shapes of most electronic signals.

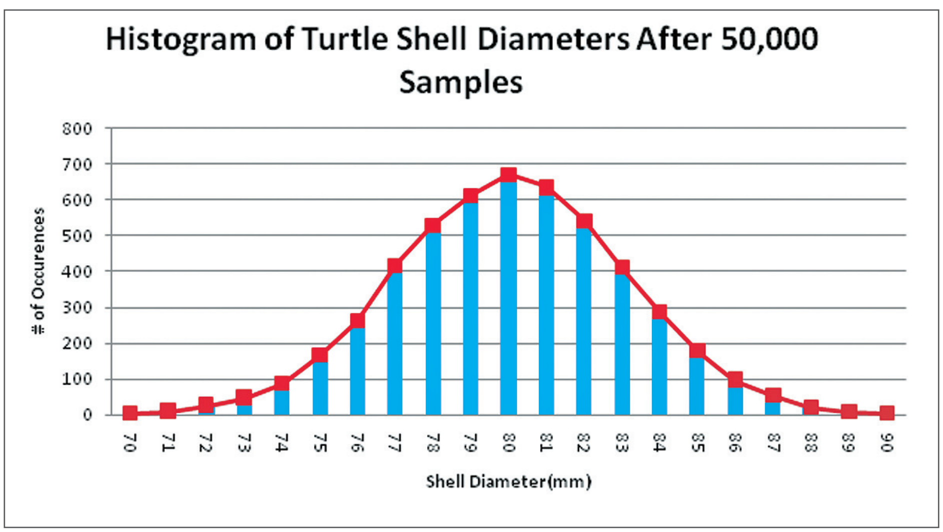


Figure 1: After 50,000 samples, the histogram of turtle shell diagrams acquires a curved shape

Gaussian theory (cont.)

From the Gaussian distribution of turtle shell sizes, we can calculate a variety of significant statistical values that describe the shape of the bell curve. The distribution will be centered at the mean value, and will diverge from the mean at a standard deviation value related to the width of the bell.

In a Gaussian distribution, 68.27% of all the shells measured (samples) will occur between one standard deviation to the left and right of the mean, as shown in Figure 2. As the number of standard deviations from the mean increases, the percentage of samples occurring between the standard deviation increases.

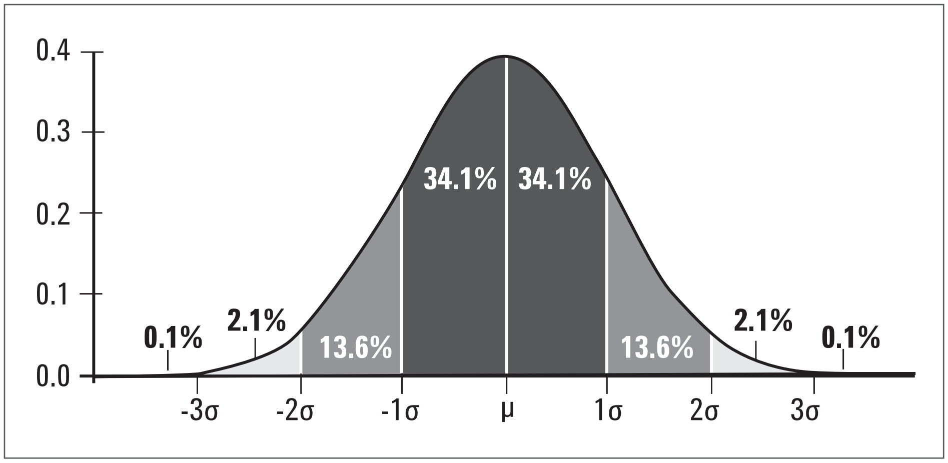


Figure 2: In a perfect Gaussian distribution 68.27% of all samples occur between one standard deviation to the left and right of the mean

Six sigma for electronic signals

In the 1980s, Motorola developed a business management strategy that used the 6σ value and applied it to manufacturing processes and business practices. This practice of achieving Six Sigma quality was very successful and has become a popular technique for increasing efficiency.

The accepted standard of achieving Six Sigma is a process that produces no more than 3.4 defects per million occurances (DPMO). This is equivalent to having 3.4 outliers for every 1,000,000 samples taken.

How can we apply the Six Sigma process to evaluating electronic signals? Imagine that instead of measuring turtle shell diameters, we measure specific attributes of each waveform of a signal. We could then determine if the attribute we are measuring meets or exceeds specified tolerances. To achieve Six Sigma quality standard for the signal, we would need to measure 1,000,000/3.4=297,117 independently- acquired waveforms. If we measure 294,117 waveforms and no defects occur, then the product is quality assured to a Six Sigma standard.

Measuring and analyzing 294,117 waveforms can be time consuming. Automated test benches using oscilloscopes on the market today can be set up to constantly measure and record data, but acquiring and analyzing 294,117 waveforms can sometimes require many hours or perhaps days of testing time to complete. After the automated tests have evaluated the waveforms you would need to check to see if any waveforms failed the specified tolerances and possibly repeat this procedure. This requires significant time spent testing signals and waiting for results, slowing time to market.

Mask testing

Another way to test your signal is with the mask testing feature of an oscilloscope. Instead of checking various parameters—such as peak-to-peak voltage, frequency, RMS voltage, and delay, what if you could simply compare your signal against a correct waveform? Mask testing allows just that. You can set up a pass/fail mask or tolerance/limit band around your signal, specifying time and voltage regions that your signals can and cannot enter, as Figure 3 illustrates.

If a glitch occurs in the signal under test and the waveform enters into the mask region, the oscilloscope alerts the user to this error. You can also set up masks around areas of the signal that should be off-limits. That way you do not need a perfect signal; just an understanding of how a signal looks when it functions correctly, as shown in Figure 4.

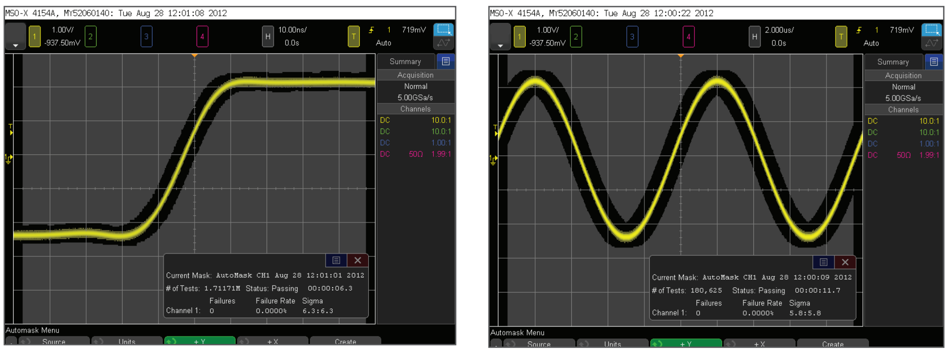


Figure 3: Mask testing compares your signal with correct signal and alerts you if your signal passes outside specific limits

Figure 4: Mask testing lets you specify areas around your signal that should be off limits

Mask testing (cont.)

Mask testing allows for flexibility in both R&D and manufacturing test. In R&D, engineers can test signals they are developing through many waveform repetitions. The more waveforms they can test, the more confidence they have that the design functions correctly. In manufacturing, engineers must test signals to ensure customers do not receive defective units. Mask testing provides more reliability than testing individual attributes because the entire signal can be evaluated against a correct signal to find glitches and/or errors. As a result, mask testing saves time and money in design and manufacturing and ensures customers receive higher-quality products sooner.

Now let's return to the analogy of measuring turtle shell diameters. Sampling turtle shell diameters is similar to sampling specific signal attributes. Let's simplify this process and instead of measuring specific signal attributes, use a mask test to qualify the signal. Rather than developing a histogram of voltage values, we would only have two outcomesfor the mask test—pass or fail. Figure 5 shows a waveform that failed mask testing.

We are no longer using a Gaussian distribution to evaluate results; instead we are implying that mask test failures occur beyond the Six Sigma limit. Recall that to achieve Six Sigma resolution you would need to test 294,117 waveforms. If we reach 294,117 passes without a single failure, then no samples occurred beyond the Six Sigma limits. Our signal is therefore quality assured to Six Sigma.

Figure 5. Mask tests make it easy to observe when a signal fails the QA process

Accelerating quality assurance

In conventional mask testing solutions, oscilloscopes typically test about 10 to 60 waveforms per second using software-based algorithms. At 60 waveforms per second (wps), the update rate on the screen is fast enough to appear responsive to our eyes but the time required to accumulate enough data to be statistically meaningful will take several minutes, or possibly hours. To acquire enough points for Six Sigma resolution—or samples of 294,117 waveforms at 60 wps—it would take almost 1.5 hours. With many different electronic signals on ICs and FPGAs, acquiring Six Sigma confidence in all the signals can take a lot of time. For example, if 10 signals needed to be probed and tested for Six Sigma quality, current solutions would take greater than 10.5 hours. If failures were found in the signals, these tests would need to be repeated, significantly multiplying the total time to acquire Six Sigma quality assurance. Although gaining Six Sigma assurance is desirable, most engineers cannot afford the luxury of waiting this long for the outcome. Keysight Technologies, Inc. has studied the current limitations of acquiring Six Sigma quality, and has created a hardware-accelerated mask testing solution that decrease this 1.5 hour test time to only 1.1 seconds.

Keysight InfiniiVision oscilloscopes are designed for the best signal visibility in the market. With an update rate of up to 1,000,000 waveforms per second, InfiniiVision 3000 X-Series scopes have less dead time and can therefore catch signal anomalies that other scopes miss. Mask testing with InfiniiVision 3000 X-Series scopes can perform hardware-based mask testing at rates up to 280,000 waveform tests per second.

Keysight InfiniiVision Series scopes are also the first scopes in the industry that can report mask test pass/fail statistics in term of sigma quality. The mask testing statistics provide the user with a variety of information including number of tests, number of failures, failure rate, and process sigma and test sigma quality factors. The process sigma is the maximum sigma resolution possible based upon the number of tests run, and the test sigma shows the actual sigma efficiency your test has achieved.

Acquiring enough samples for Six Sigma resolution using an InfiniiVision 3000 X-Series scope takes only 1.1 seconds (depending on the timebase setting, this 1.1 second is best–case at 10 ns/div). Figure 6 shows a test of 1 million waveforms (in a little under 4 seconds) that provides resolution to 6.2 sigma.

Keysight InfiniiVision oscilloscopes provide another benefit; lower inherent vertical noise than competitive scopes. This is important because lower noise impacts the quality and precision of mask testing. Vertical noise can cause random increases (spikes) in all areas of the signal, including trigger timing issues. A consistent trigger point is vital to prevent jitter and drift of the waveforms. If a signal drifts outside the mask limits due to noise and/or trigger jitter, mask testing will analyze the ocilloscope-induced error components as a failure, thereby corrupting the test results. A low noise floor is essential to attain the precision and reliability of Six Sigma testing.

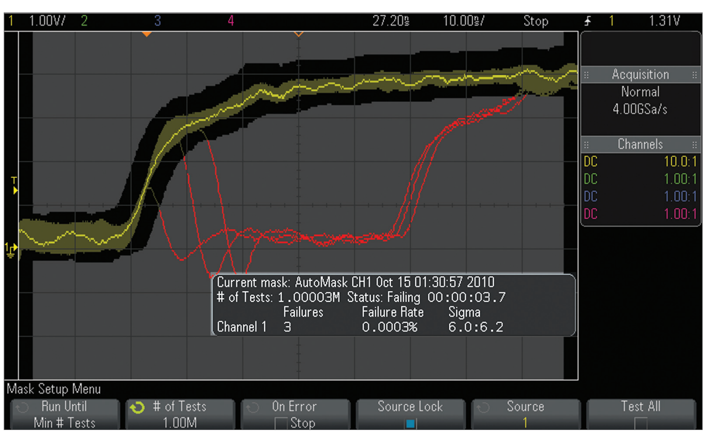


Figure 6: Mask testing to 6.2 σ resolution takes only seconds using an InfiniiVision scope with a mask test rate of 270,000 waveforms tests per second

Conclusion

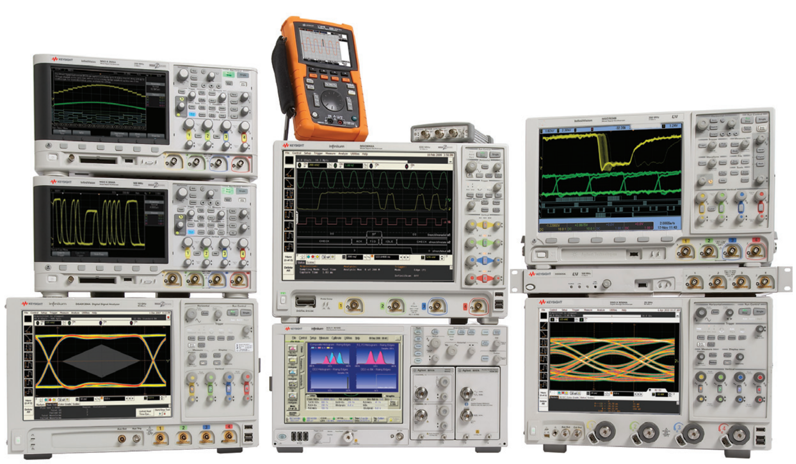
Not only does Keysight provide the fastest, low-noise mask testing performance in the market, but the mask test application on InfiniiVision scopes also has a variety of features for customizing the test procedure. You can setup the mask test to run for a specified time, until a specific number of tests have occurred, or until a certain process sigma threshold is reached. InfiniiVision oscilloscopes also offer you the option to continue running upon a failure, stop on a failure, or save the data on a failure. For example, if the purpose of the mask test was to ensure Six Sigma efficiency, you can set the scope to run until a process sigma quality factor of six is achieved. This will occur after approximately 294,117 waveforms have been tested. If a failure occurs within these tests the waveform would automatically be stopped or saved for viewing and analysis later.

The capability to assure the quality of products to Six Sigma in 1.1 seconds saves time and effort in R&D and manufacturing. In R&D, engineers can test signals they are developing through many waveform repetitions. The more waveforms they can test, the more confidence they have that the design functions correctly. In manufacturing engineers must test signals to ensure customers do not receive defective units.

Mask testing lets engineers spend less time in the R&D lab ensuring signal stability, and in manufacturing probing for signal reliability. Your company saves manpower hours and can invest the capital in profitable initiatives, such as new product design. At the same time, customer satisfaction will increase as you produce high-quality products and move them quickly into the market.

Related literature

Publication title	Publication type	Publication number
Mask Test for InfiniiVision Series Oscilloscopes	Data sheet	5990-3269EN
InfiniiVision 2000 X-Series Oscilloscopes	Data sheet	5990-6618EN
InfiniiVision 3000 X-Series Oscilloscopes	Data sheet	5990-6619EN
InfiniiVision 4000 X-Series Oscilloscopes	Data sheet	5991-1103EN
InfiniiVision 6000 X-Series Oscilloscopes	Data sheet	5990-4087EN
Oscilloscope Waveform Update Rate Determines Probability of Capturing Elusive Events	Application note	5989-7885EN



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