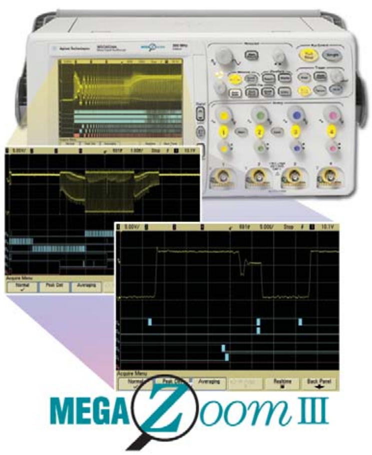
Oscilloscope Display Quality Impacts Ability to Uncover Signal Anomalies

Agilent 6000 Series Scope versus Tektronix TDS3000 Series Scope

Application Note 1552



Introduction

The quality of your oscilloscope's display can make a big difference in your ability to troubleshoot your designs effectively. If your oscilloscope has a low-quality display, you may not be able to see critical signal anomalies. A scope that is capable of showing signal intensity gradations can reveal important waveform details, including signal anomalies, in a wide variety of both analog and digital signal applications.

This application note compares display quality for a variety of analog and digital signals using Agilent's 6000 Series mixed signal oscilloscope (MSO) and Tektronix' TDS3000 Series scope. In some examples, we also show the results displayed on a traditional analog oscilloscope. We also discuss a methodology for quantifying display quality to make it easier to compare scope displays objectively.

The third dimension: intensity modulation

Engineers traditionally think of digital storage oscilloscopes (DSOs) as two-dimensional instruments that graphically display voltage versus time. But there is actually a third dimension to a scope: the z-axis. This third dimension shows continuous waveform intensity gradation as a function of the frequency of occurrence of signals at particular X-Y locations. In analog oscilloscope technology, intensity modulation is a natural phenomenon of the scope's vector-type display, which is swept with an electron beam. Due to early limitations of digital display technology, this third dimension, intensity modulation, was missing when digital oscilloscopes began replacing their analog counterparts. Now, it is making a comeback.

Display intensity gradation can be extremely important when you are looking for signal anomalies, especially when you are viewing complex-modulated analog signals such as video, read-write disk head signals, and digitally controlled motor drive signals. Intensity gradation is also helpful in a wide variety of mixed-signal applications found in embedded microprocessor and microcontroller technologies common in the automotive, industrial, and consumer markets. But even when you are viewing purely digital waveforms, intensity gradation can show statistical information about edge jitter, vertical noise, and the relative occurrence of anomalies.

Recently, all major digital oscilloscope vendors have begun to provide z-axis intensity gradation – with varying degrees of success – in order to emulate the display quality of an analog oscilloscope.

Complex-modulated analog signal applications

If you are working with complex-modulated signals, you need a scope with sufficient display quality to let you look at the big picture and then zoom in to see the details.

Composite video signals

Many engineers are familiar with standard NTSC or PAL composite video signals, which are complex-modulated analog signals. Figure 1 shows one frame of composite video photographically captured from an analog oscilloscope's display. Even though the display "flickers" when you view this waveform at 5 ms/div, there is important information embedded within the displayed waveform envelope. An experienced video design engineer can quickly determine the quality of analog signal generation from this display.

Figure 2 shows an older digital oscilloscope display without z-axis intensity modulation. Although this scope has sufficient sample rate and memory depth to capture details of this signal even at 5 ms/div, all captured points are displayed with the same display intensity. Waveform detail within the signal's envelope is visually lost. Given a choice between analog oscilloscope technology and older digital display technology, it's no surprise that today's video labs are filled with analog oscilloscopes!

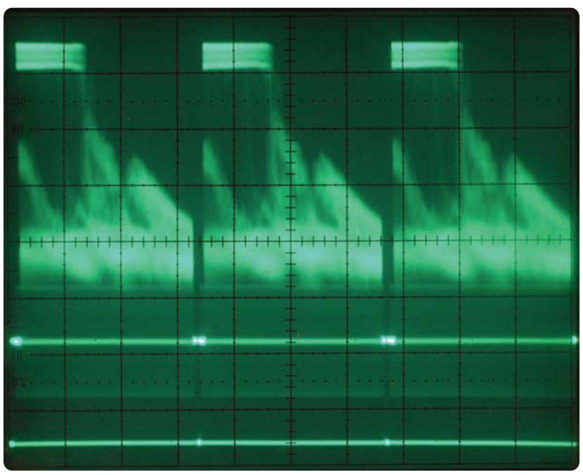


Figure 1. Full frame of composite video displayed on a 100-MHz analog oscilloscope

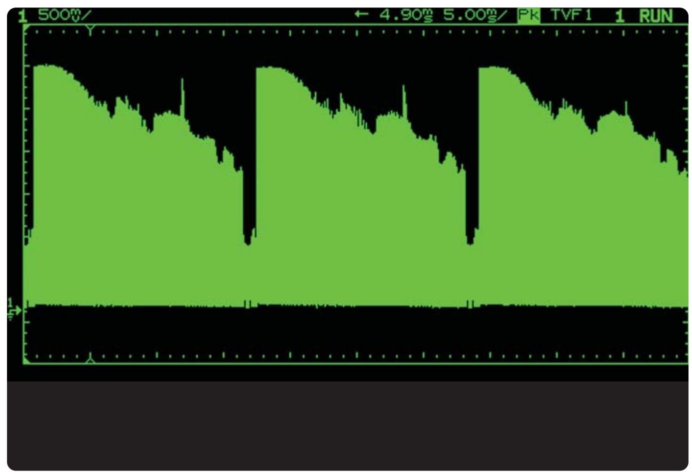


Figure 2. Full frame of composite video displayed on an older digital oscilloscope without intensity gradation capability

However, the visual quality of an analog oscilloscope's display has finally been matched in a digital oscilloscope. Figure 3 shows the real-time capture of a video signal using Agilent's 6000 Series oscilloscope. This scope uses Agilent's proprietary MegaZoom III technology that provides up to 256 levels of color intensity gradation for each pixel based on deep memory acquisitions (up to 8 MB) mapped to a high-resolution display (XGA). This digital oscilloscope can display a repetitive analog signal with quality similar to (or perhaps better than) an analog oscilloscope, and it can also capture, display, and store complex single-shot signals with the same visual resolution. This is where conventional analog oscilloscopes fall short of their digital counterparts. Analog scopes can only display repetitive waveforms. Figure 4 shows a zoomed-in/windowed display of a single line of the composite video captured from the same acquisition that is shown in Figure 3. But since analog oscilloscopes can't digitally store waveforms, we are unable to show a similar zoomed-in single-shot display using an analog oscilloscope.

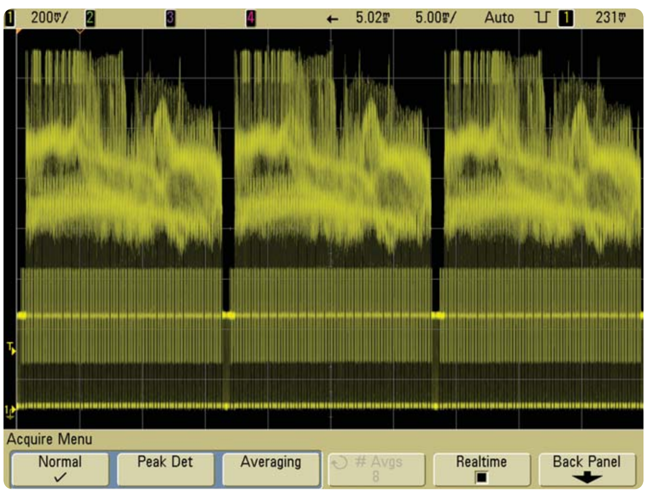


Figure 3. Full frame of composite video displayed on Agilent's 60000 Series scope

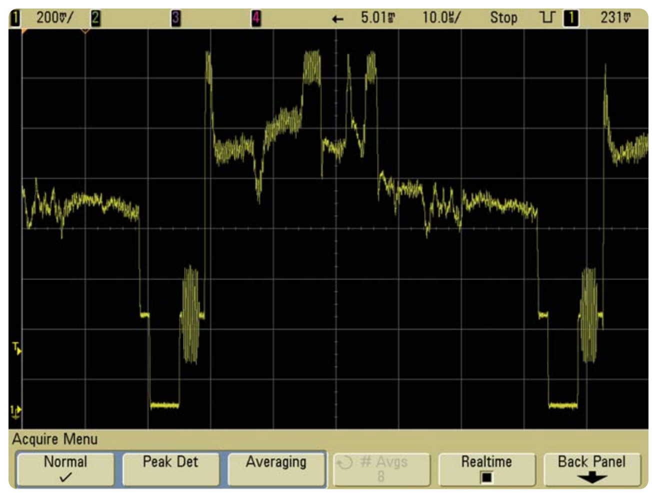


Figure 4. Zoomed-in display of a single line of video using Agilent's 6000 Series scope

Figure 5 shows an attempt to repetitively capture this same composite video signal using a Tektronix TDS3000 Series oscilloscope, which Tektronix classifies as a digital phosphor oscilloscope (DPO). Tektronix introduced DPO technology to attempt to emulate the display quality of an analog oscilloscope. Although the quality of the DPO display far exceeds that of older digital scopes (Figure 2), we think it falls short of the quality of either Agilent's MegaZoom III technology or of an analog scope's display quality. We encourage you to judge for yourself. But just like an analog oscilloscope, DPO technology in the TDS3000 Series oscilloscopes requires repetitive/equivalent-time acquisitions in order to effectively produce displays with intensity gradations. But if you captured this signal using a single-shot acquisition, you would observe a waveform very similar to Figure 2, but with a few levels of intensity grading. In addition, if you attempt to zoom-in on a captured waveform to view just a single line of video, you will see only widely spaced dots, as shown in Figure 6. This is because this scope has limited memory depth (10 k maximum) and it reduces its sample rate for viewing relatively long and complex waveforms such as this composite video signal. In this particular case, the sample rate was reduced to just 250 kSa/s, even though this scope's specified maximum sample rate is in the range of Giga samples per second. Deep memory, which is available in Agilent's 6000 Series oscilloscopes, enables you to capture the "big" picture (Figure 3) and then zoom-in on "small/detailed" areas (Figure 4) – with sufficient waveform detail – using sustained high sample rates.

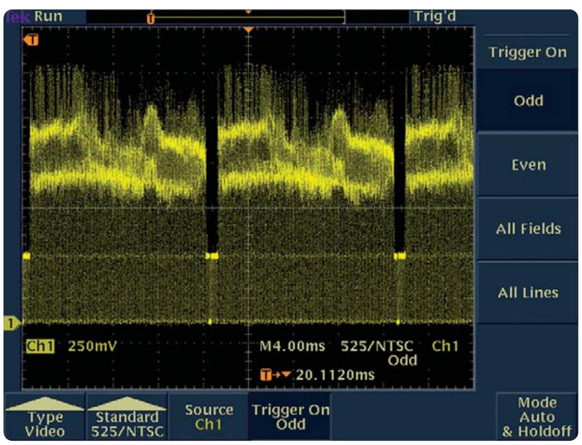


Figure 5. Full frame of composite video using the Tektronix TDS3000 Series DPO scope

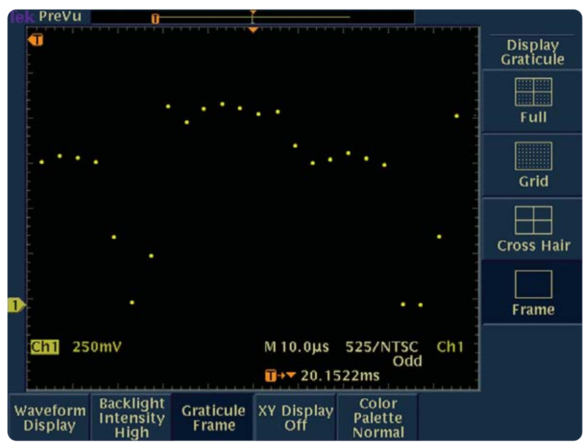


Figure 6. Zoomed-in display of a single line of video using the Tek TDS3000 Series scope (note: dots have been enhanced for clarity)

Digitally controlled motor drive signal
Another example of a complex analog signal is a digitally controlled motor drive signal. A one-time start-up cycle of a motor would be classified as a single-shot phenomenon. Figure 7 shows how Agilent's 6000 Series mixed signal oscilloscope (MSO) is able to reliably capture one phase of this single-shot start-up motor drive signal. You can also use this scope's digital/logic channels to synchronize and trigger the waveform capture based on the digital control signals of the motor. This capability can be extremely important when you attempt to synchronize acquisitions on not only power-up sequences, but also on particular motor positioning commands. Although not shown, this oscilloscope could just as easily capture all three phases of the motor drive signals simultaneously using its four channels of analog acquisition.

Also shown in Figure 7 are two zoomed-in images taken from the same single-shot acquisition. With this scope's MegaZoom III technology, we can see a bright vertical vector (near the center of the display) in the middle image after zooming-in by a factor of 100. Further waveform expansion (20,000:1) on the pulse-width modulated (PWM) burst reveals a glitch, as shown in the image on the right.

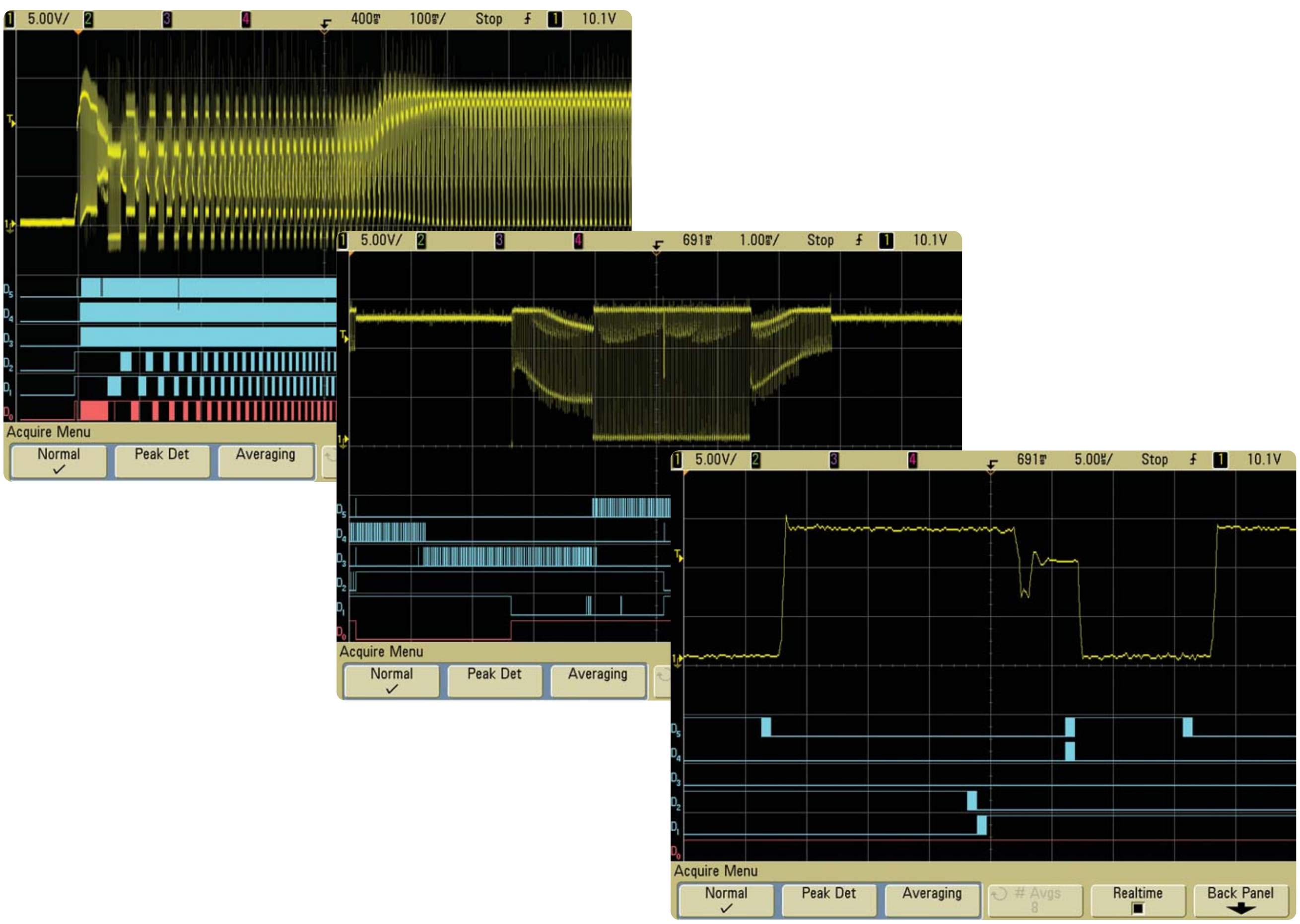


Figure 7. Motor drive signal start-up sequence with digital control signal triggering and various levels of zoom to reveal "runt" pulse using Agilent's 6000 Series MSO

As shown in Figure 8, the Tektronix TDS3000 Series scope is unable to capture all the details of this signal because of insufficient sample rate and display quality. In addition, the TDS3000 Series scope lacks the additional logic channels of an MSO, so you cannot trigger the acquisition on the digital control signals of this three-phase motor. The poor image quality is due to this scope's limited memory depth and reduced sample rate on slower time base ranges, and also due to the fact that this scope's DPO display technology is primarily based on repetitive acquisitions. Because of this scope's reduced sample rate (10 kSa/s), no attempt was made to zoom-in on this waveform since you could only observe a few widely spaced dots – similar to Figure 6. Also, no attempt was made to capture this signal on an analog scope since our signal was single-shot and a conventional analog oscilloscope is incapable of displaying a single-shot waveform.

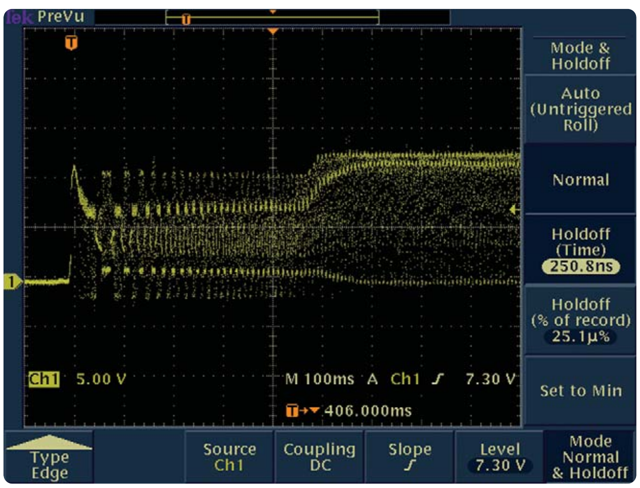


Figure 8. Start-up motor drive signal captured using a Tektronix TDS3000 Series scope

Digital signal applications

The visual effects of a digital oscilloscope's intensity gradation capability are most dramatic when you view complex-modulated analog signals such as the composite video and motor drive signals just shown. However, intensity gradation is also extremely important for uncovering signal anomalies when you are debugging digital circuitry. Figure 9 shows an example of uncovering a runt pulse embedded within a pulse-width modulated signal (PWM). The bright spot near the center of each burst is an indication that our scope has captured a signal anomaly. By zooming-in on one of the bright spots, we can clearly see details of the signal anomaly, as shown in Figure 10. Although an analog oscilloscope will also show the bright spots with repetitive sweeps, the analog scope is incapable of zooming-in on stored waveforms.

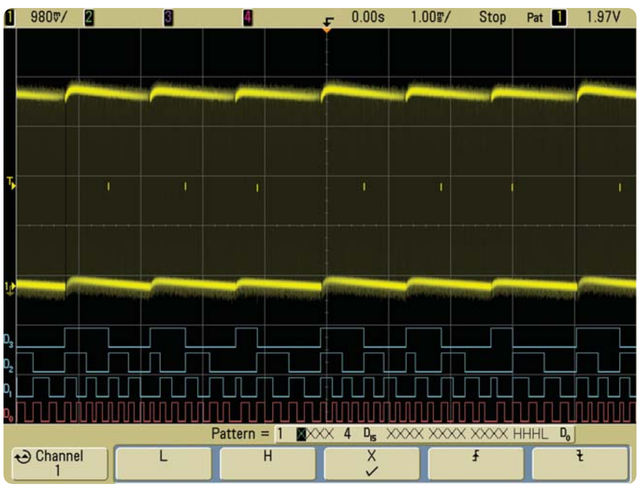


Figure 9. Agilent 6000 Series scope reveals "bright spots" buried within each digital burst

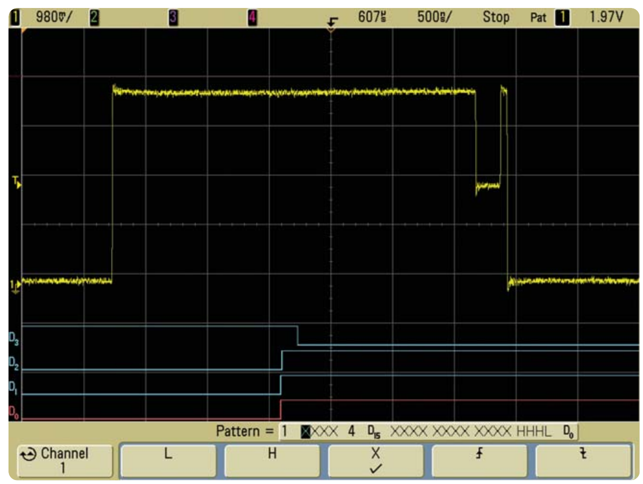


Figure 10. Zooming-in on a "bright spot" reveals a runt pulse

Figure 11 shows the Tektronix TDS3000 Series scope's attempt at capturing the same digital waveform information. This scope does not have sufficient display resolution to show the bright spots. It also lacks sufficient acquisition memory depth and sample rate at this time base setting to reveal the runt pulse after zooming in, as shown in Figure 12.

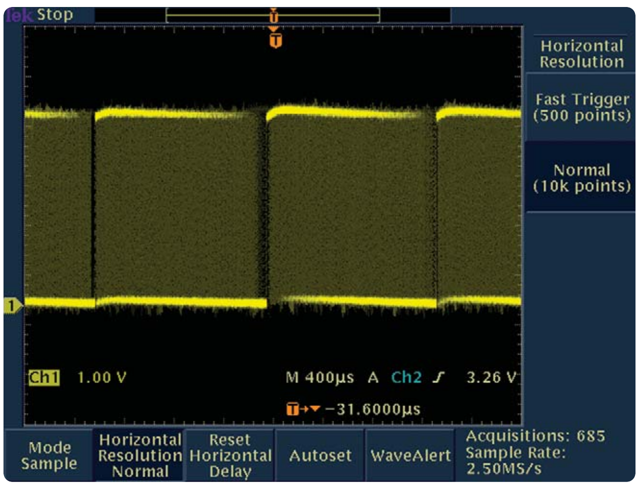


Figure 11. The Tek TDS3000 Series scope fails to reveal any embedded "bright spots"

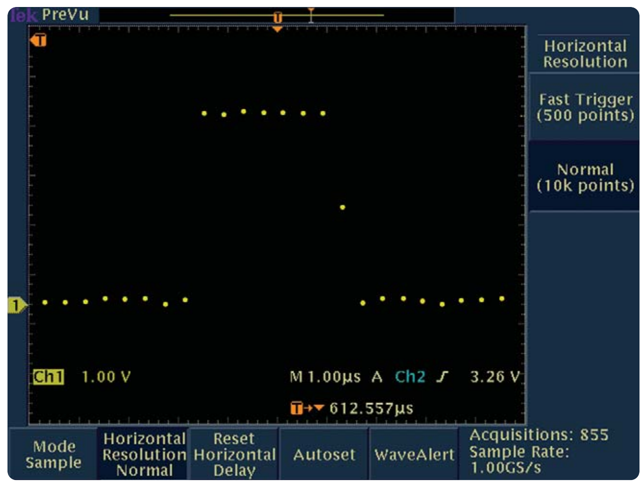


Figure 12. Zooming-in on the burst shows just a single digitized point on the runt pulse due to insufficient sample rate and memory depth (note: dots have been enhanced for clarity)

Display intensity gradation is also very important when you view waveforms that contain jitter, noise, and infrequent events. Levels of display intensity can help you interpret the relative frequency of occurrence of signal anomalies, and sometimes it can help you visually determine the type of jitter or noise in your system – based on display intensity dispersion – without resorting to sophisticated waveform analysis software.

Figure 13 shows an example of a digital signal that includes timing jitter (near the left side of screen), vertical noise (top and bottom of waveform), and a very infrequent glitch (near the center of screen). Because of the relative dimness of the displayed glitch, we know that this particular glitch occurs very infrequently. We can also see that the nature of the jitter is very complex and probably includes a large component of deterministic jitter (DJ). If the dispersion of display intensity on the signal's edge appeared to be Gaussian in distribution, we would suspect that the jitter might be dominated by random jitter (RJ). For a more in-depth discussion on the different types of jitter, refer to Application Note 1448-2, "Finding Sources of Jitter with Real-Time Jitter Analysis," listed at the end of this document.

Figure 14 shows the same signal displayed on an analog oscilloscope. Unfortunately, we are unable to show the jittering edge because it occurs before the trigger reference point (rising edge). But the signal edge that sometimes produces the infrequent glitch can be viewed. However, we can't see the glitch on the analog scope's display because it occurs too infrequently for conventional analog scope technology to display, even with the display intensity adjusted to full brightness.

The Tek TDS3000 Series scope was also not able to capture and display the infrequent glitch even though we held a probe on the test point for more than 10 seconds. However, the glitch capture problem was not due to insufficient display quality. The problem was associated with insufficient waveform update rates. For a more in-depth discussion on this important aspect of digital oscilloscopes, refer to Application Note 1551, "Improve Your Ability to Capture Elusive Events: Why Oscilloscope Waveform Update Rates are Important," listed at the end of this document.

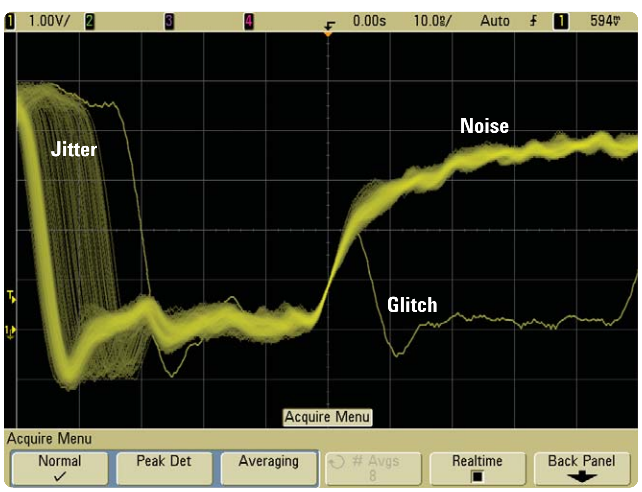


Figure 13. Display intensity gradation shows characteristics of jitter, noise, and signal anomalies on Agilent's 6000 Series oscilloscope

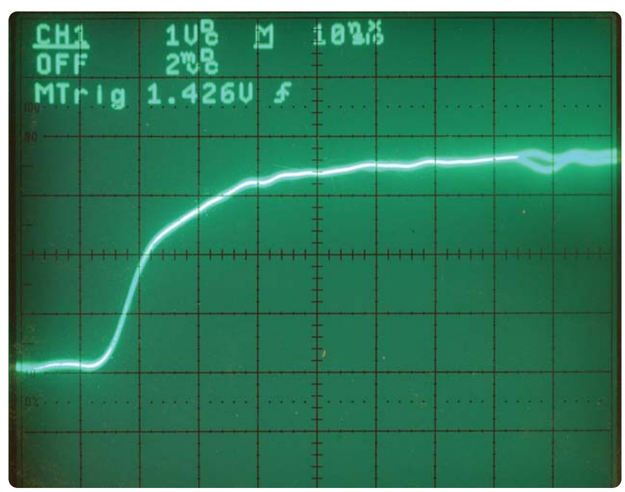


Figure 14. The analog oscilloscope fails to show the infrequent glitch

Quantifying display quality

The quality of an oscilloscope's display is primarily a subjective issue. The best way to compare display quality between various digital oscilloscopes is to use them side-by-side and make visual comparisons using a variety of signals, as we have shown in this application note. But evaluating digital scopes from different vendors side-by-side is not always possible.

Rather than just making a bold claim that one particular scope has better display quality than another scope, we will attempt to quantify display quality for comparison purposes. There are three primary aspects of a digital oscilloscope that contribute to display quality: number of display pixels, number of intensity levels, and number of digitized points mapped to the scope's display. Since Agilent's 6000 Series scopes utilize an XGA display (768x1024), you might intuitively deduce that these scopes have a display resolution of 786,000 pixels. However, not all of these pixels are used for waveform display. Since some of the pixels are allocated for out-of-graticule menu graphics, just 640x1000 out of the 768x1024 pixels are used for waveform display. In addition, since this scope's real-time digitization is based on an 8-bit analog-to-digital converter, only 256 vertical pixels out of the available 640 vertical pixels are actually used in the vertical axis for real-time waveform display. This leaves us with a maximum net waveform pixel resolution of 256,000 pixels to which up to 8,000,000 digitized points are mapped in real-time.

Mapping up to 8,000,000 digitized points into 256,000 pixel locations means that when viewing complex signals many pixels within the scope's vertical scaling range will receive multiple "hits" for each acquisition of the scope. The number of hits each pixel receives determines the degree of intensity grading. The Agilent 6000 Series scopes specify 256 levels of intensity grading. If a particular pixel gets hit just one time, it receives the minimum viewable level of intensity. Pixels that receive 256 or more hits receive the maximum level of intensity. By multiplying the scope's pixel resolution with the levels of intensity grading, we can quantify relative display quality of a digital oscilloscope. Using this formula, we compute that the Agilent 6000 Series scope has approximately 65 M pixel-levels of display quality.

So, how does this compare to the display quality of Tektronix' TDS3000 Series oscilloscope? Since the TDS3000 Series scopes utilize a VGA display (640x480), the maximum number of display pixels is approximately 300,000 pixels. But making the same assumptions concerning allocation of menu graphics and bits of analog-to-digital conversion (8 bits), we estimate that the TDS3000 Series scopes may use up to 115,000 pixels for real-time waveform display. The TDS3000 Series scopes then map up to 10,000 digitized points to these pixel locations during each repetitive acquisition cycle. Although Tektronix does not explicitly specify the number of display intensity levels, we estimate that this scope utilizes no more than 16 levels of intensity gradation. Using these assumptions, we estimate that this scope has approximately 1.8 M pixel-levels of relative display quality. Without even considering the significant difference in memory depth between these two digital oscilloscopes, the relative display quality of the Agilent 6000 Series oscilloscopes are more than 35 times better than the Tek TDS3000 Series oscilloscopes based on these assumptions and calculations for repetitive acquisitions. But for real-time single-shot applications, Agilent's display quality is even higher (compare Figure 7 with Figure 8) since Agilent maps 8,000,000 digitized points to its display as opposed to mapping just 10,000 points using the Tektronix TDS3000 Series oscilloscope.

Summary

When considering the purchase of your next digital oscilloscope, don't consider just bandwidth, sample rate, number of channels, and memory depth. Another very important criteria is display quality. An oscilloscope's third dimension, the z-axis, which shows intensity gradation of signals based on frequency-of-occurrence, can reveal important waveform details, including signal anomalies, in a wide variety of both analog and digital signal applications. In this application note, we have attempted to show qualitative comparisons using Agilent's MegaZoom III technology compared to both analog oscilloscope technology and Tektronix's DPO display technology. In addition, we have presented a quantitative measure of display quality (pixel-levels) for relative comparisons.

To view an on-line video that demonstrates the importance of display quality and waveform update rates, go to **www.agilent.com/find/scope-demo**, and then click on the video titled, "Expanding Beyond Two Dimensions."

Glossary

Equivalent-time sampling digitizing an input signal repetitively using multiple acquisition cycles

MegaZoom III technology an Agilent proprietary acquisition and display technology that provides a digital storage oscilloscope with extremely fast waveform update rates (up to 100,000 real-time waveforms per second) and a high-resolution display quality that meets or exceeds the display quality of traditional analog oscilloscopes

Intensity gradation a variation of display intensity at particular X-Y or pixel display locations based on the signal's frequency-of-occurrence at these locations

Mixed signal oscilloscope (MSO) an oscilloscope with additional channels of logic timing analysis with direct time-correlation and combinational logic/pattern triggering across both analog and digital inputs

Pulse-width modulation (PWM) a technique where widths of digital pulses are varied; when filtered, they generate varying levels of DC voltage

Real-time sampling digitizing an input signal from a single-shot acquisition using a high rate of sampling

Related Literature

Publication Title	Publication Type	Publication Number
Agilent 6000 Series Oscilloscopes	Data Sheet	5989-2000EN/ENUS
Oscilloscope Display Quality Impacts Ability to Uncover Signal Anomalies - Agilent 6000 Series Scopes versus LeCroy WaveSurfer 400	Application Note	5989-2004EN
Improve Your Ability to Capture Elusive Events: Why Oscilloscope Waveform Update Rates are Important	Application Note	5989-2002EN
Deep Memory Oscilloscopes: The New Tools of Choice	Application Note	5988-9106EN
Ten Things to Consider When Selecting Your Next Oscilloscope	Application Note	5989-0552EN
Finding Sources of Jitter with Real-Time Jitter Analysis	Application Note	5988-9740EN

Product Web site

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(fax) (080) 769 0900

Latin America:
(tel) (305) 269 7500

Taiwan:
(tel) 0800 047 866
(fax) 0800 286 331

Other Asia Pacific Countries:
(tel) (65) 6375 8100
(fax) (65) 67556 0042
Email: tm_ap@agilent.com
Contacts revised: 1/12/05

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