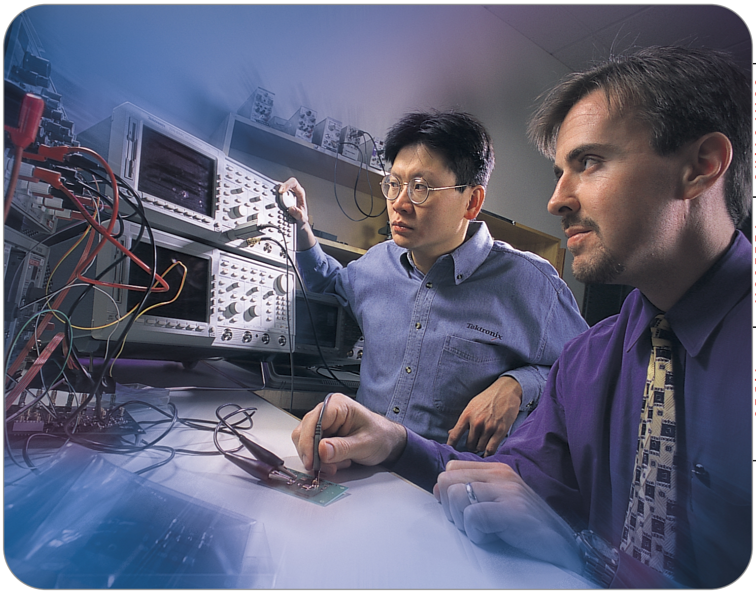
Understanding and Performing Precise Jitter Analysis



Featuring the TDS7000 Oscilloscopes

Rapidly ascending clock rates and tighter timing margins are creating a need for jitter and timing measurements in mainstream circuits.

Introduction

Jitter in the 100 ps range would be a non-issue for an application with a 50 MHz clock and a period of 20 ns. Within this data-valid window, you can have nanosecond rise and fall times, with setup times also in the nanosecond range.

Now compare that to an application with a 400 MHz clock with a clock period of just 2.5 ns. Suddenly, you are faced with sub-200 ps rise times and setup times that can be seriously distorted by 100 ps of jitter. Properly characterizing what was once “insignificant” jitter is now crucial for proper circuit operation.

One of the most convenient tools for making precise jitter and timing measurements is an oscilloscope. However, there are a myriad measurement techniques and concepts involved in making these measurements and analyzing the results.

This application note will clarify jitter analysis by discussing the applications, specifications and issues surrounding the following:

- Cursor-based jitter and timing analysis
- Automatic jitter and timing analysis
- Histogram technique jitter and timing measurements
- Single-shot jitter and timing analysis
- Data jitter timing analysis
- Precise Bus timing analysis

Jitter Basics

Jitter is defined as either the deviation of a signal's transition from its ideal position in time or the timing variation from transition to transition. Jitter sources include power supply noise, ground bounce and V_{dd} noise. Ground bounce shifts the V_{cc} and Gnd levels in a circuit.

Phased locked loops (PLL) are one type of circuit employed in a wide variety of designs that depend upon these reference levels for a stable frequency output. Shifts in the V_{cc} and Gnd level can easily change threshold crossing levels in a PLL, affecting the transition time and resulting in jitter. Crystal references are prone to thermal and mechanical noise. And crosstalk from adjacent lines can couple into the lines of interest.

Whatever its source, jitter can significantly reduce margin in an otherwise sound design. For example, excessive jitter can increase the bit error rate (BER) of a communications signal by incorrectly transmitting a data bit stream. In digital systems, jitter can violate timing margins, causing circuits to behave improperly. As a consequence, measuring jitter accurately is necessary to determine the robustness of a system and how close it is to failing.

Jitter appears as multiple transitions on an oscilloscope display. This distribution of transitions contains statistical information like standard deviation, peak-peak deviation, maximum deviation, minimum deviation and population of transitions. Measuring and understanding each of these statistics is key to properly characterizing jitter.

Cursor-based Jitter and Timing Analysis

The cursor measurement technique for quantifying jitter is the simplest and most easily understood way to make jitter timing estimates. Although this application note will cover many other methods for measuring jitter, this time-tested technique remains a perfectly legitimate alternative.

For example, communications engineers might use cursors to measure the quality of their transmission signals by measuring the jitter of their eye-diagrams. Or digital designers would rely on cursors to determine the setup and hold timing of their designs.

Performing Cursor Timing Measurements

Extremely easy to perform, cursor measurements of jitter require setting an oscilloscope to infinite persistence mode and then using the cursors. Figure 1 shows the Tektronix TDS7000 oscilloscope performing a jitter measurement on a clock signal. The cursor readout tells the engineer the period jitter (1.4 ns) and the available margin. This cursor technique can be used to perform eye-diagram zero crossing jitter and also setup and hold timing measurements.

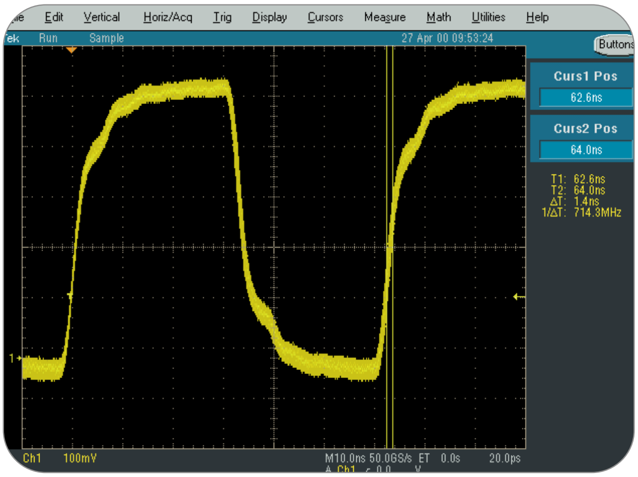


Figure 1 – *Estimating jitter using measurement cursors.*

Pros and Cons

Most oscilloscope users clearly understand this measurement technique. The cursor measurement technique quickly provides a very good first order estimate of the jitter performance. It works well for quickly making setup and hold timing measurements and clock stability measurements. If using this jitter measurement technique allows you to pass all your jitter specifications, you are virtually assured a robust design.

The usefulness of the cursor measurements for jitter depends on the oscilloscope being used. Industry-leading digital phosphor oscilloscopes (DPOs) like the TDS7000 series have trigger jitter of 6 ps RMS. This instrument can be very useful for performing precise jitter measurements with cursors.

Most real-time digital oscilloscopes, however, have trigger jitter of 10 ps RMS. Assuming a ±5 sigma pk-pk, this translates to ~100 ps of peak-peak trigger jitter. With a 50 MHz clock, this is not a concern. With 400 MHz clocks and 100 ps peak-peak jitter specifications, this amount of trigger jitter becomes unacceptable.

Also remember that complete jitter characterization requires statistical analysis – something the cursor technique does not provide. The cursor technique is also unable to provide analysis on specialized signals like spread spectrum clocks.

Automatic Jitter and Timing Analysis

To obtain statistical information about a jitter waveform, many engineers use the automatic measurements offered by most digital oscilloscopes. This technique is the simplest way to make automated jitter measurements.

Automatic jitter measurements are very appealing because the user gets the statistics about the jitter distribution at the push of a button. A semiconductor engineer, for example, may use automatic jitter measurement to look at the performance of a PLL to determine if the period stability of the crystal is within specifications. Automatic measurements can also be used to view data-valid window parameters like rise time, duty cycle and pulse width. Also, channel to channel measurements like delay time.

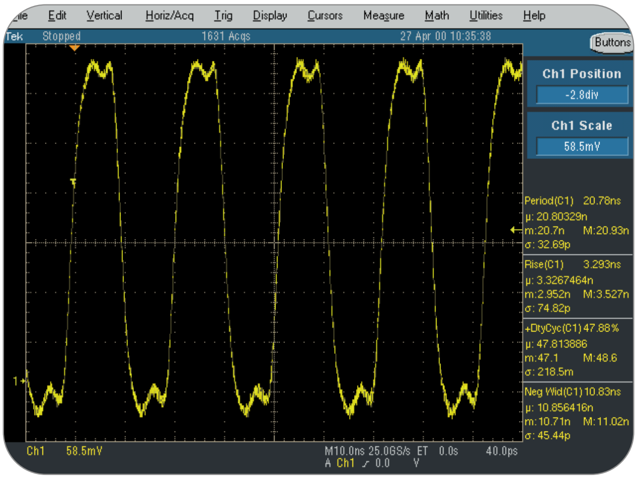
Performing Automatic Jitter Measurements

Figure 2 shows the Tektronix TDS7000 performing an automatic period measurement on a test crystal. In this example, the ideal clock period is 20 ns. The automatic measurements show that the mean(m) period is 20.80 ns, with a standard deviation(s) of 32.69 ps. Knowing sigma, one can calculate the probability of the crystal exceeding the specifications. A good rule of thumb is to estimate pk-pk to be ±5 sigma.

To determine what the multiplier is for your particular system, collect a statistically significant population and divide the pk-pk jitter by the standard deviation.

Pros and Cons

The biggest plus about automatic measurements is that a designer can get jitter statistics at the push of a button. Like the cursor method described above, it is a very good first order estimate of the jitter in a signal. Although this is a perfectly valid timing measurement technique, it does not supply some of the jitter details designers might need. The missing information includes which cycles are being measured or the ability to perform contiguous cycle measurements.



► ***Figure 2 –*** *Automatic timing measurement.*

Histogram Technique Jitter and Timing Measurements

Using histograms and histogram statistics to measure jitter adds a new dimension to jitter analysis. Now, the engineer can actually see the distribution in a histogram plus get statistical jitter information. This technique is often used by memory designers who need to look at setup and hold times. Communication designers rely on histogram jitter analysis to examine the eye opening of their data streams.

Performing Histogram Timing Measurements

Jitter can be measured with the histogram technique, as shown in Figure 3. In this example, the data hold-time jitter is measured on CH2 relative to the clock on CH1. The histogram provides a qualitative distribution of jitter in the data signal relative to clock. The histogram statistics allow further analysis of the timing between clock and data. As described earlier, jitter is statistical in nature and gathering more samples increases statistical confidence. A DPO like the TDS7404 will rapidly increase the sample size by acquiring 400,000 waveforms/second.

Pros and Cons

Histogram jitter and timing analysis is a very useful technique that can return precise measurement results and display the histogram view. In particular, it provides the standard deviation statistic at a very obvious threshold that can then be used to "predict" the jitter performance of a circuit. This technique is also very useful for performing setup and hold time measurements and clock stability measurements.

A detailed write-up of this technique can be viewed in the application note at: http://www.tektronix.com/Measurement/App_Notes/dpo/jittermeas/eng/

However, the histogram technique is still affected by trigger jitter and cannot perform analysis on spread spectrum clocks nor on contiguous clock cycles.

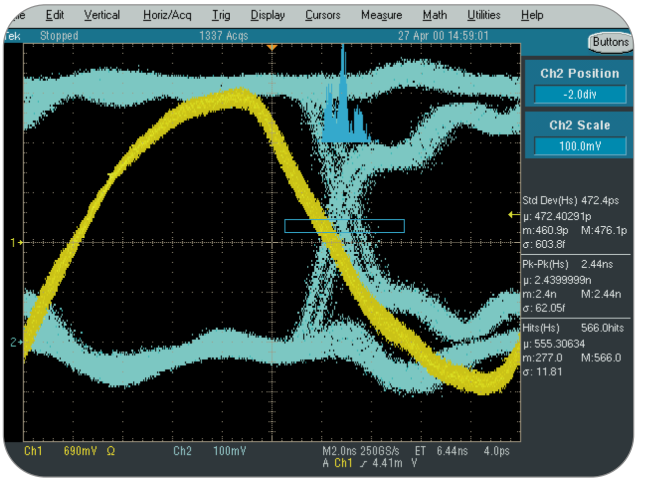


Figure 3 – *Histogram Timing Measurement.*

Single-Shot Jitter and Timing Analysis

As signal rates increase, the need for more sophisticated methods of measuring jitter are now emerging. Specifically, users are finding they need a way to measure jitter on a single waveform acquisition.

A more detailed write-up of this measurement technique can be found at: http://www.tektronix.com/Measurement/App_Notes/jitter/eng/jitter.html

This measurement technique, performed by the Tektronix TDSJIT2 jitter measurement software, measures jitter on each and every period in an acquisition waveform the length of which can range from 500 to 32 million points.

Jitter measurements can be performed on all contiguous cycles in a single *triggered acquisition*. This allows jitter measurements to be made on adjacent periods of a clock, providing a modulation view of the clock as well as other capabilities like jitter trending.

Performing Ultra-high Accuracy Jitter Measurements

In Figure 4, a Tektronix TDS7000 series oscilloscope equipped with the new Tektronix TDSJIT2 jitter measurement package analyzes a 400 MHz clock. The RMS error is 4.3 ps. Because trigger jitter is not a factor in the measurement process, TDS7000s with TDSJIT2 can measure down to 1 ps RMS jitter. In addition, note the detailed cycle-cycle jitter statistics and the rise-time of each and every individual rising edge in the waveform acquisition.

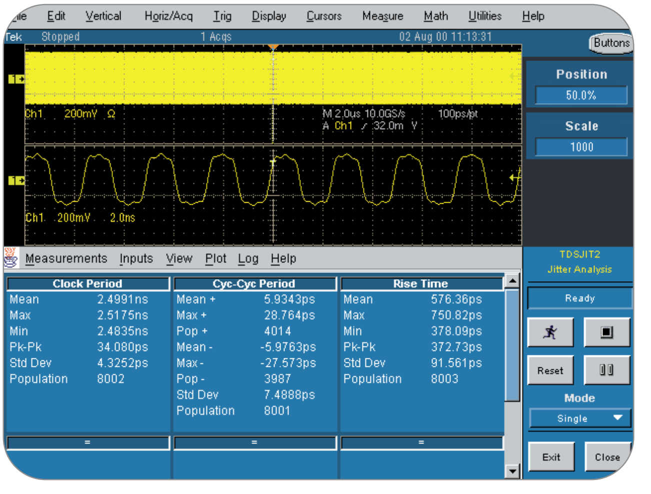
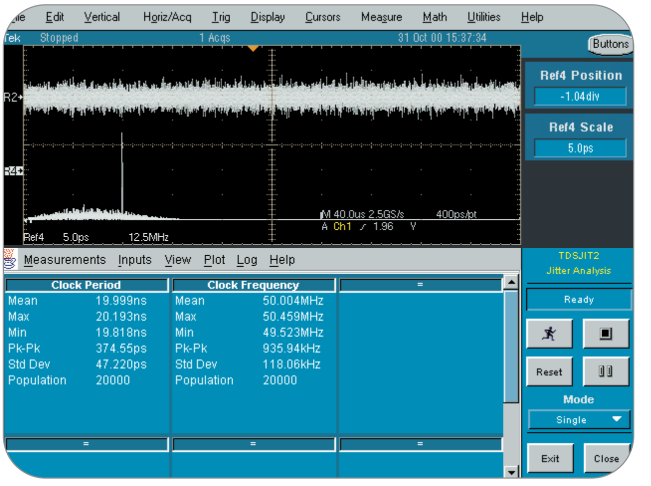


Figure 4 – *Single-shot jitter measurements with TDSJIT2.*

Performing Ultra-Long Record Jitter Measurements

In Figure 5, the analysis was performed on approximately 8000 cycles in a single-shot acquisition of 400 K record length. For low-speed jitter modulation like power supply coupling, a single-shot acquisition can be performed on up to 32 MB record lengths. A Jitter Spectrum analysis can also be performed with TDSJIT2 that returns the jitter frequency content of the signal. This technique can be used to characterize intentional modulation like spread-spectrum clocks or unintentional modulation like power-supply coupling. Figure 5 shows a modulated clock with a spur at 25 MHz.



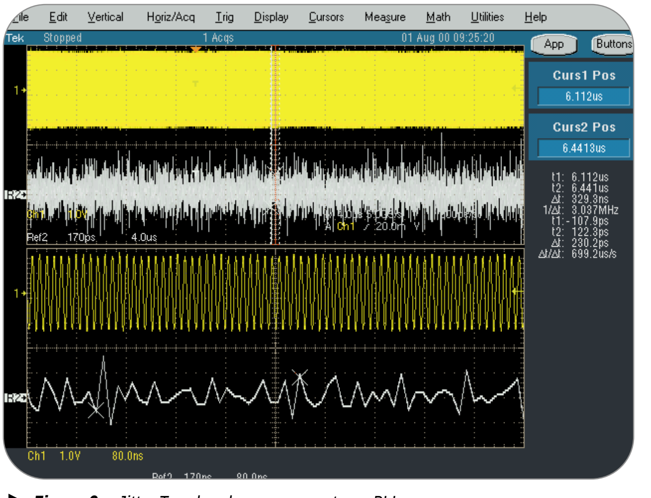
▶ ***Figure 5 –*** *Jitter spectrum of modulated signal.*

Performing Jitter Trending

Figure 6 shows a PLL output on CH1. R2 shows the cycle-cycle period jitter trend of CH1. R2 is the cycle-cycle jitter of CH1 correlated in time with CH1.

The Zoomed waveforms provide more detailed information about particular cycles of interest.

The Paired Cursor measurements show: 329.3 ns on the horizontal scale between two particular cycles of interest and 230.2 ps of cycle-cycle jitter difference. Also, you can see the individual cycle-cycle jitter values of the two particular cycles of interest (–107.9 ps, 122.3 ps).



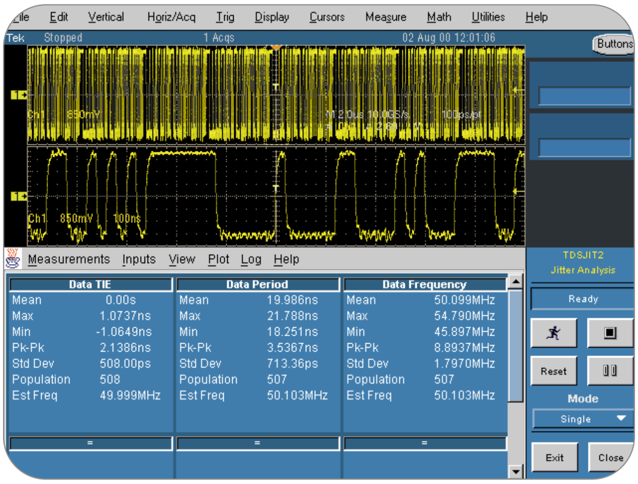
▶ ***Figure 6 –*** *Jitter Trend and measurements on PLL.*

Pros and Cons

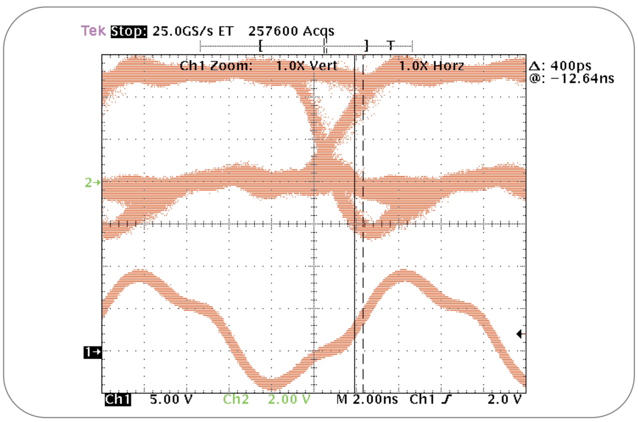
Measurements like N-cycle jitter and jitter analysis on contiguous clocks can only be made using this measurement technique. As a result, it is the only viable way to measure jitter for certain applications. If spread spectrum clocking (SSC) is implemented, for example, the only way to “back-out” the modulation effects is to make delta period measurements on adjacent clock cycles. Also, a quick way to analyze unintended modulation is to plot a trend of the single-shot jitter, then graph the jitter spectrum.

The single-shot jitter measurement technique also allows unprecedented timing accuracy due to the demise of trigger jitter in the analysis. The world-class Tektronix TDS694C or TDS7404 can easily measure jitter down to 1.5 ps RMS with this measurement technique.

Note that if the “non-singleshot” measurement techniques mentioned above pass specifications, there is really not a need to perform these ultra-precise single-shot jitter measurements. This is especially true if you have little or no modulation in your design.



▶ ***Figure 7 –*** *Data jitter analysis on a 50 Mb/s data stream.*



▶ ***Figure 8 –*** *Oscilloscope performing timing measurement with cursors.*

Data Jitter Timing Analysis

Engineers working on serial data streams often have to perform “data jitter” measurements. In this case, the signal under analysis does not have a clock and the jitter analysis method has to perform clock recovery.

Performing Data Jitter Measurements

In Figure 7, the new Tektronix TDSJIT2 jitter measurement package is performing a data jitter analysis on a 50 Mb/s data stream. The long data packet and the zoomed details are shown above the analysis results. The TIE (Time Interval Error) analysis results show the jitter of each data transition relative to a calculated clock edge.

Pros and Cons

Data streams with no available clock have special challenges in determining the proper data transition point. The data jitter measurement technique extracts a best-fit clock and uses it to determine the ideal data transition point.

Data jitter performed on very long data packets is susceptible to error due to the oscilloscope reference timebase. Industry leading oscilloscopes like the TDS7404 have 1.5 ppm crystals that add minimal error while performing timing measurements over very long durations.

Precise Bus Timing Analysis

Figure 8 shows the output of an oscilloscope performing a simple setup or delay time measurement. The oscilloscope’s infinite persistence mode was used to capture the data, and cursors are used to determine the minimal delay time. Because the waveform is derived from repetitive acquisitions, the data points where the cursors are located probably did not occur on the same acquisition. Look carefully at the scattering of points to the right of the positive transition. Where would you place the cursor? Which data transition do you pick – positive or negative? How does the timing margin change from one acquisition to the next? What if qualifiers were needed for making the measurement?

The above questions are answered in Figure 9.

Performing Bus Timing Analysis

Figure 9 shows the new TDSJIT2 application performing a precise setup timing measurement. TDSJIT2 allows the unprecedented capability to:

- Define the individual transitions of interest for analysis. In this case, only the falling edges of CH1 and the rising edges of CH2.
- Define the timing window for analysis. In this case, only timing transitions that occur between 200 ps and 3 ns.
- Add a Qualifier signal. In this case, CH3 must be High.
- Add Cursor Gating. In this case, analyze only transitions between the cursors.

Oscilloscope Specifications That Impact Jitter Measurements

Timing Accuracy

Timing accuracy is the most important specification for single-shot timing measurements because it determines how close these measurements will be to the real values. It takes into account both the repeatability and resolution specifications.

Timing accuracy is based upon a number of factors, including sample interval, time base accuracy, quantization error, interpolation error, amplifier vertical noise, and sample clock jitter. Each of these factors contributes to the timing error. The combination of all these factors results in the timing accuracy specification.

For example, the timing accuracy specification for the Tektronix TDS694C and TDS7404 oscilloscope is 3 ps RMS using the TDSJIT application. This specification has been tested under varying input conditions. Depending upon the input applied, the TDS7404 and the TDS694C have the ability to measure down to 1.5 ps RMS jitter.

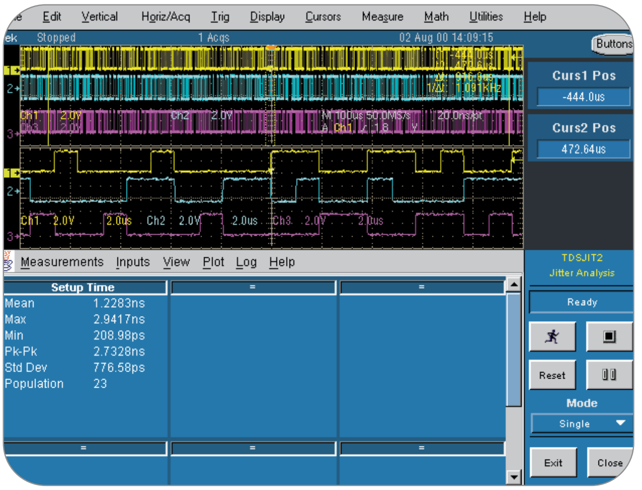


Figure 9 – *TDSJIT2 setup timing measurement with 4 qualifiers: edge transition, valid timing window, level qualifier and cursor gating.*

Conclusion

Many oscilloscope techniques have been developed to perform proper jitter and timing measurements. Each has its pros and cons. Tektronix provides a suite of timing measurement techniques to allow you to choose the one that works best for your measurement environment. As a result, designers and engineers using Tektronix oscilloscopes can be assured that they have the best techniques available, and the most accurate results.

The Tektronix TDS7000 oscilloscopes have a robust set of jitter measurement features – a comprehensive TDSJIT2 application, the lowest trigger jitter and best timing accuracy of any real-time oscilloscope available, an extremely high-speed 20 GS/s, 4 GHz acquisition engine, and 32 MB record length. This feature set allows you to make an array of jitter measurements with unprecedented accuracy and ease.

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