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EDN

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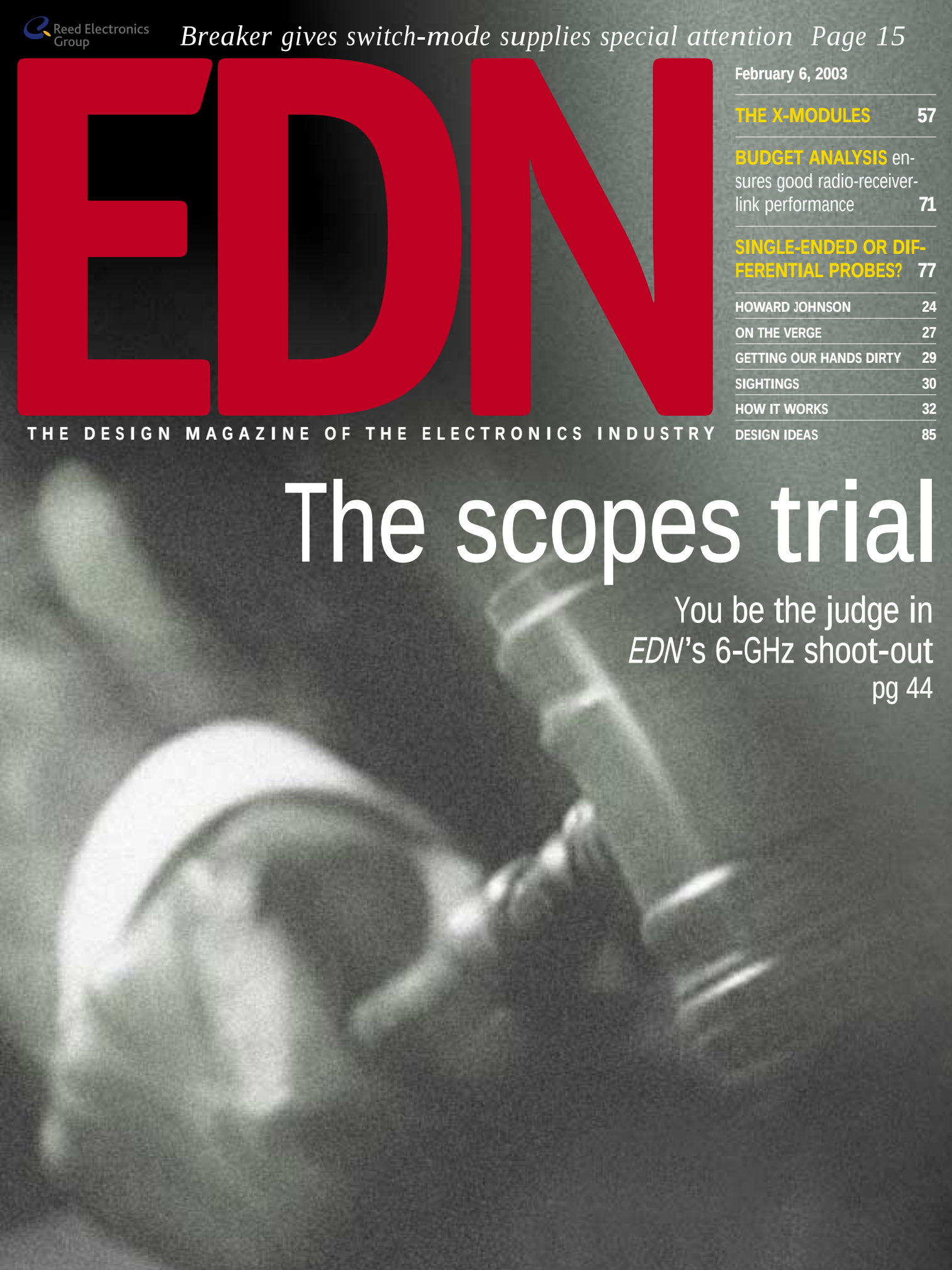


The scopes trial

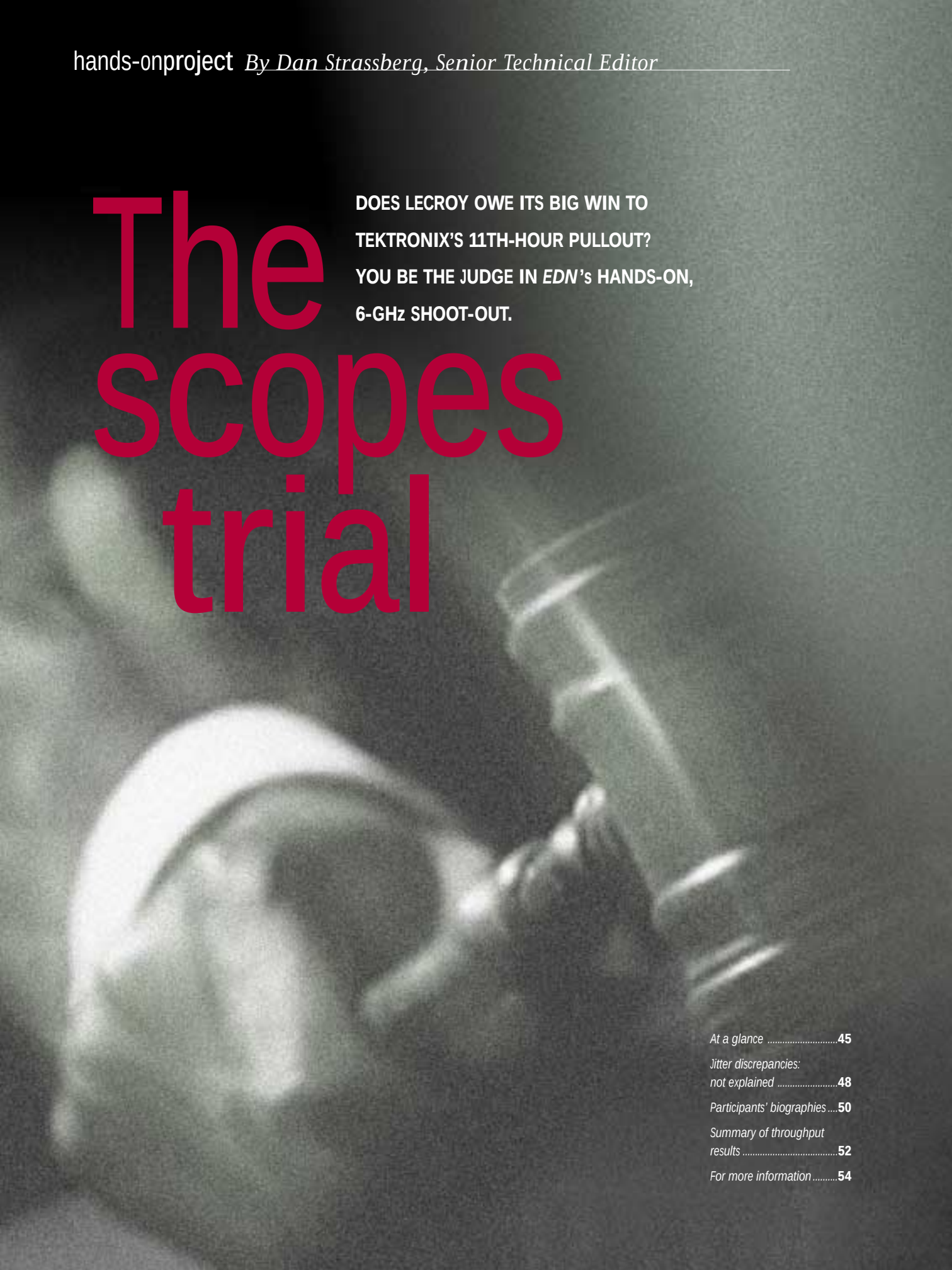
You be the judge in *EDN*'s 6-GHz shoot-out

pg 44

hands-on**project** *By Dan Strassberg, Senior Technical Editor*

The scopes trial

DOES LECROY OWE ITS BIG WIN TO TEKTRONIX'S 11TH-HOUR PULLOUT? YOU BE THE JUDGE IN *EDN*'s HANDS-ON, 6-GHz SHOOT-OUT.



The plans for a hands-on shoot-out between what were then the world's only two 6-GHz-bandwidth real-time-sampling digital oscilloscopes—Tektronix's TDS 6604 (**Figure 1**) and LeCroy's Wavemaster 8600A (**Figure 2**)—began to take shape in mid-August of 2002. Agilent had kept news of its Infiniium 54855A (**Figure 3**), under such tight wraps that the press would not get word of it until several weeks later. Only a couple of weeks earlier, on July 30, the day before the 8600A's public announcement, LeCroy had visited *EDN*'s offices to demonstrate the new scope and, for comparison, had brought along a Tek scope. A 6604 wasn't available, so the company's director of product management, Mike Lauterbach, PhD, had brought an older, narrower bandwidth Tek unit, the 4-GHz-bandwidth TDS 7404.

Lauterbach readily conceded that, in generating complex displays that involve a lot of data processing—a key application for high-end scopes—the 6604 is much faster than the 7404. He said, however, that in creating such displays, the 8600A was still approximately an order of magnitude faster than the 6604. He also emphasized how important it is for a scope to rapidly put meaningful displays on the screen. Scopes have been a mainstay of EEs for more than half a century. A key reason for this enduring popularity is the highly interactive nature of using a scope.

You observe something on the scope display. If what you see is a problem, you hypothesize a fix for it. If it's unexpected behavior of the UUT (unit under test), you think up a new measurement to confirm the suspected cause. Either way, you can immediately try out your idea. Without this level of immediacy and interactivity, the lab experience takes on an entirely different character. LeCroy is hardly alone in recognizing the importance of scope interactivity; the need for this capability motivated Tektronix to incorporate the DPO (digital-phosphor-oscilloscope) mode in the TDS 7000 series, of which the 7404 but not the 6604 is a member. Unfortunately, some of the most valuable scope features are unavailable in the DPO mode.

Although its bandwidth is lower than the 8600A's and 6604's, the 7404, with deep-memory options, offers much greater memory depth than does the 6604. (The 7404's standard memory depth is 100k samples/channel in four-channel mode, optionally expandable to 32M samples in the single-channel mode.) In several respects, the deeper memory makes the 7404 more directly comparable to the 8600A, whose standard memory depth is 1M sample/channel in the four-channel mode and optionally as much as 48M samples/active channel in the two-channel mode. In the two-channel mode, both the 8600A and the 6604 acquire data in real time at a maximum rate of 20G samples/sec, whereas the 7404 can sample at that rate in the single-channel mode.

The 7404 and 8600A use true deep-memory architectures, but the 6604 uses an architecture known as FISO (fast in/slow out). In contrast with deep-memory scopes, which digitize in real time, FISO scopes acquire samples in real time but store the samples in analog form before digitizing them at rates that—at high sweep speeds—are usually slower than the acquisition rate. (Many FISO scopes, including the 6604, also offer a random-repetitive-sampling mode, which can further boost the effective rate of sampling repetitive waveforms. Random-repetitive sampling is also a feature of many deep-memory scopes. Both the 7404 and the 8600A offer it.) The 6604 provides a fixed memory depth of 125,000 samples/channel. This depth and the normal maximum real-time sampling rate (10G samples/sec on each of four channels), double when you operate the scope in the two-channel mode.

AT A GLANCE

- LeCroy's Wavemaster 8600A 6-GHz-bandwidth real-time-sampling DSO handily bested Tektronix's TDS 6604 in eight tests of the scopes' speed of producing meaningful displays. (One test used Tek's TDS 7404 instead of the 6604.)
- Were it not for Tektronix's last-minute withdrawal from the shoot-out, the results might have been at least a little different. Certainly, a Tek representative could have helped with using the Tek products more effectively.
- We were left with one baffling inconsistency: The scopes provided widely varying assessments of the random and deterministic components of the jitter in a repetitive, 622-Mbps, pseudorandom binary sequence.
- These high-end scopes do a superb job of placing at your fingertips a dazzling array of measurement and analysis functions, but the instruments are extraordinarily sophisticated, and experience with them helps enormously in using them effectively.

THE GAME PLAN

After the 8600A's public announcement, a Tek representative was eager to demonstrate that LeCroy was wrong about its claims about the greater speed at which its new scope generates complex displays. The 8600A's predecessor product, the 5-GHz-bandwidth Wavemaster 8500, had been available for many months. Its architecture and the speed at which it generates displays are the same as those of the 8600A, and Tek had had ample opportunity to determine what the 8500 could do.

Each company proposed a list of tests (**Table 1**) and agreed to send two engineers each to meet at *EDN*'s Newton, MA, office to use both the 8600A and the

6604 and perform both sets of tests to see which scope was faster at creating useful displays. With LeCroy's agreement, Tek later proposed bringing a CSA 7404 in addition to a 6604. The CSA 7404 is a version of the TDS 7404 that offers enhanced waveform-analysis capabilities. The CSA unit would enable Tek to demonstrate the responsiveness of its top-of-the-line deep-memory scope. As the arrangements moved forward, *EDN*'s sibling publication, *Test & Measurement World*, agreed to participate in and co-sponsor the event.

Figure 1

Tektronix's TDS 6604 was the first four-channel, real-time-sampling, 6-GHz-bandwidth DSO.

Figure 2

LeCroy's Wavemaster 8600A was the top performer in *EDN*'s two-scope 6-GHz shoot-out.

At this point, the situation suddenly became more complex. A phone call from Agilent revealed that that company was about to introduce its own four-channel, 6-GHz-bandwidth DSO (**Reference 1**). I offered to include Agilent in the shoot-out, and the company initially expressed interest, but the logistical problems proved insurmountable. I would have had to inform Tek and LeCroy of Agilent's participation. In so doing, I would have revealed Agilent's plans to its competitors as much as six weeks before the company's planned Nov 1 announcement. This schedule proved unworkable, so we agreed that, if the company wanted us to do so, we could later stage a second round of the shoot-out and publish the results. Only Agilent would participate, but the tests would be the same as those we had run on the Tek and LeCroy scopes. Currently, it is unclear whether Agilent is interested in such a project, but if the company wants to proceed, you will read about Round Two in *EDN*.

As the plans progressed, Tektronix developed reservations about participating. Some people speculated that perhaps the shoot-out's premise was naive. Tektronix is the established market leader. It had gotten its 6-GHz scope to market approximately a year before LeCroy. Customers had enthusiastically received the product, and almost everyone who has used it respects it. (Even LeCroy has called the TDS 6604 a fine scope—though pointing out that "fine" is not a synonym for "best available.") So, with no guarantee that its product would solidly trounce the competition, what could Tektronix possibly gain from participating in a shoot-out?

In the end, Tek withdrew, saying that it had had no opportunity to evaluate the 8600A's brand-new SDM (serial-data-measurement) option, which is LeCroy's answer to the CSA 7404's advanced analysis capabilities. The option was too new for Tek to have tried it, and both companies had agreed to bring products only if the competitor could have evaluated them. LeCroy's proposed tests didn't require the option's presence, but Tek proposed several tests that involved serial-data analysis. LeCroy said that, for this purpose, it would use an option that Tek had had ample time to evaluate—JTA2 (jitter timing and analysis)—which had been available since LeCroy announced the Wavemaster series in March 2002. (On the Tek scopes, equivalent functions are available via the JIT3 option, which we used to compare the two manufacturers' scopes' speed of serial-data analysis.) Moreover, LeCroy said that it would disable SDM, which it could easily do from the 8600A's main menu, Still, Tek continued to object, perhaps because it misunderstood LeCroy's proposal.

TABLE 1—SUMMARY OF THE EIGHT TESTS

TESTS PROPOSED BY LECROY	TESTS PROPOSED BY TEKTRONIX
Amplitude and rms measurements on a 5.2-GHz sine wave, taken over a 60-sec interval	Differential rise-time measurement with scopes in single-shot mode
Period and frequency measurements on a 5.2-GHz sine wave, taken over a 60-sec interval	Building an eye diagram on a 2.5-Gbps PRBS7 (127 bit) serial data stream for 60 sec (LeCroy SDM option turned off)
FFT measurement on 5.2-GHz sine wave	Building an eye diagram on a 2.5-Gbps PRBS7 (127 bit) serial data stream for 60 sec (LeCroy SDM option turned on at LeCroy's request)
Math calculations, such as computing squares of signals and summing them	Time interval error (jitter) measurement on a 622-Mbps serial data stream

WHAT REALLY HAPPENED

Despite Tek's withdrawal, the shoot-out took place on schedule. LeCroy owns a TDS 7404 equipped with JIT3 and as much memory (8M samples/channel) as the scope can accommodate. LeCroy also happened to have a rented TDS 6604 and was able to extend the rental period by several days. Unfortunately, JIT3 was not enabled on this scope. At 8 a.m., Tuesday, Oct 29, 2002, the two LeCroy representatives appeared with the two Tek scopes, a WaveMaster 8600A containing the JTA2 and SDM options and a carload of signal sources (**Figure 4**; see **sidebar "**Participants' biographies").

The project yielded much interesting and useful data, but the data would have undoubtedly been more interesting and useful had Tek at least sent an observer. (After Tek withdrew, *EDN* extended such an invitation—in time for a Tek repre-

sentative to make the trip—but received no response.) A Tek observer likely could have shown where we were going wrong in using the Tek scopes. That advice might have kept the results from so overwhelmingly favoring LeCroy. Each company had proposed six tests, and, in two days, we ran four tests from each company's list on each 6-GHz scope. (One of Tek's proposed tests required using the 7404 rather than the 6604.)

We couldn't perform the full slate of 12 tests because time didn't permit it and because we eliminated any test that we couldn't perform on both the 8600A and at least one of the Tek scopes. We used the TDS 7404 for only one test, which the available 6604 wouldn't run because its capabilities to produce a frequency plot of the jitter or the period or half-period duration. A frequency plot can point you to a source of periodic jitter, such as a clock from a switching power supply.

JITTER DISCREPANCIES: NOT EXPLAINED

By Martin Rowe, Test & Measurement World

Everyone agrees that jitter affects data integrity and often affects data-transfer rates in digital-communications systems, but not everyone agrees on how to measure jitter or how to interpret the measurements. I never saw that more clearly than in the jitter measurements we made with the two scopes.

We used both scopes (Table A) to measure jitter in a 622-Mbps, PRBS7 (repetitive 127-bit, pseudorandom binary sequence) data stream. Although both scopes report similar total jitter, the table shows that the components of jitter differ drastically. The results are consistent, though, with the general formula used to describe total jitter (Reference A): T_j (total jitter)$_j$ = D_j (deterministic jitter) + 14·R_j (random jitter).

WHO'S RIGHT?

In truth, we don't know whether either scope accurately reported D_j and R_j or if neither scope was right. To find an explanation for the discrepancy, I asked several jitter experts. (You can find an analysis developed by one of the participants, LeCroy's chief scientist, Marty Miller, PhD, at the HTML version of this article at *EDN*'s Web site, www.edn.com, along with detailed results of the shootout.) Tom Zych, a systems engineer at Amherst Systems points to the algorithms that the scopes use to extract R_j and D_j. He notes that, because engineers don't agree on how to extract R_j and D_j, you shouldn't be surprised that the two instruments produce different results.

The lack of agreement among engineers over jitter algorithms explains why Amherst Systems' jitter-analysis software lets you use any of three algorithms. Zych believes that the Tektronix scope uses a fourth algorithm, which, as far as he knows differs substantially from those that LeCroy uses. Tektronix would comment neither on its algorithm nor the discrepancies.

Michael DeBie, formerly with Wavecrest and now a signal-integrity consultant, argues that an arbiter could have helped decide which scope (if either) was right. A BERT (bit-error-rate-test) scan, performed with a BER tester, might reveal clues, but none was available for our tests (Tektronix had been scheduled to bring one.) Jitter analyzers, such as those made by Wavecrest or GuideTech, use edge timing to measure jitter and extract its components, and those instruments might also act as arbiters.

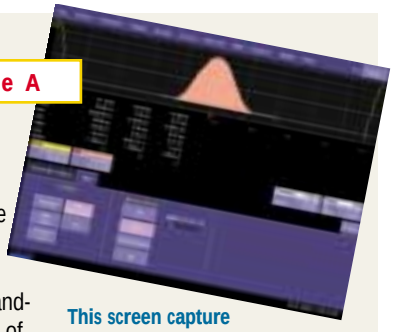
Because it can provide greater detail in both amplitude and time, a sequential-equivalent-time-sampling scope, such as an Agilent digital communications analyzer or a Tektronix communications-signal analyzer, might also help to explain the discrepancy, says DeBie. (Sequential equivalent-time-sampling scopes can have bandwidths almost 10 times those of the scopes tested and can also digitize at significantly higher resolution, but they do not digitize in real time or anything close. Maximum sampling rates are typically around 200k sample/sec. Moreover, these scopes usually acquire only one sample after each trigger event. This characteristic normally limits the instruments to highly specialized applications, such as device characterization.)

IS A SCOPE USEFUL?

You use a scope to troubleshoot circuits, and the point of extracting D_j from the total jitter is to unmask clues about the source of jitter. A further breakdown of jitter components can help you isolate jitter sources. Both scopes use other tools that can help you find the source of jitter. For example, you can produce a histogram such as the one in Figure A. The histogram contains a "shoulder" to the left of the peak. This non-Gaussian curve indicates that the jitter contains a nonrandom component.

To isolate a periodic, non-Gaussian characteristic in jitter, you can use the scope's FFT

Figure A



This screen capture from the LeCroy Wavemaster 8600A shows a histogram (rose-colored curve at top center) of time-interval errors in a 622-Mbps PRBS7 data stream. Surrounding the histogram is the jitter bathtub curve (in yellow at the far left and right). Beneath these curves are the statistics for the group of approximately 2 million measurements from which the scope constructed the curves in approximately 1 minute.

TABLE A—DIFFERING ASSESSMENTS OF A PRBS7'S DATA STREAM'S JITTER

Scope/option	Tektronix TDS 7404/JIT3	LeCroy Wavemaster 8600A/JTA2
T_j	44.28	39.09
R_j	1.18	3.36
D_j	27.79	5.87

All measurements are in picoseconds, rounded to two decimal places.

Reference

A. Wavecrest Corp, Eden Prairie MN, *Jitter Fundamentals*, www.wavecrest.com/technical/pdf/jittfun_hires_sngls.pdf.

Author's biography

Martin Rowe is the senior technical editor at Test & Measurement World. *He holds a BSEE from Worcester Polytechnic Institute (Worcester, MA) and an MBA from Bentley College (Waltham, MA). He has held engineering positions at several test-and-measurement companies and has been writing for* Test & Measurement World *for more than 10 years.*

JIT3 option wasn't enabled. The 8600A handily won every test related to the shoot-out's original purpose: assessing the speed at which the scopes presented data (see **sidebar** "Summary of throughput results"). The 8600A's minimum victory margin was 2.1-to-1 in a test that LeCroy proposed. The maximum margin was 651-to-1 in a test that Tek proposed.

Note, however, that to achieve the 651-to-1 result, LeCroy used the SDM option. As indicated, had Tektronix been present, it would have objected to LeCroy's use of this option. Using JTA2 to make a similar measurement, LeCroy's victory margin was a still convincing but less dramatic 6.5-to-1. You can find detailed results, including screen images as well as analysis and commentary by LeCroy's Marty Miller, PhD, on the Web (**Reference 2**).

PARTICIPANTS' BIOGRAPHIES

Michael Lauterbach, PhD, is director of product management for LeCroy Corp. He has worked at LeCroy for more than 20 years, starting as manager of engineering services. His doctorate from Yale University (New Haven, CT) is in high-energy physics. Lauterbach has published more than 30 papers on the use of digital test equipment for a variety of applications. He has presented more than 100 seminars at technical conferences and at leading electronics companies worldwide.

Martin T Miller, PhD, chief scientist at LeCroy Corp, has been a hands-on engineer and designer at the company for more than 25 years. His doctorate from the University of Rochester (Rochester, NY) is in high-energy physics. A native of Baltimore, Miller has contributed analog, digital, and software designs, though in the most recent 15 years he has focused on measurement-and-display software capabilities for LeCroy scopes. He holds several US patents and sits on IEEE standards committee TC-10 (IEEE Standards 1057-1994, 1241, and 181/194-1997 concerning waveform digitizers).

THE LEARNING CURVE

What might have happened if Tek, instead of LeCroy, had been the *only* manufacturer that participated? No one can be sure, but Tek probably would have done better not only than it did, but also than it would have if it had participated along with LeCroy. That the outcome should favor the sole participant has nothing to do with cheating; as far as we know, none took place. Moreover, we have no reason to suspect that Tek would have cheated had *it* been the sole participant.

The issue is the learning curve for using extraordinarily sophisticated instruments. Both companies have done a superb job of creating user interfaces that simplify invoking the scopes' enormous range of advanced measurement and analysis capabilities. Still, nothing can substitute for hands-on experience with the model of instrument you are using. Although the LeCroy representatives had some experience with the Tek scopes, they were more familiar with their own products. Tek representatives would have been more familiar with Tek's scopes. Almost certainly, any company's representatives would be more adept at getting the best results from their own products than from a competitor's.

Therefore, after Tek withdrew, we told the company several times that, if it has any problem with our methodologies or reported results, we invite it to send us material stating its position so that we can publish the material on or link to it from our Web site (**Reference 2**). Our offer stands.

A BAFFLING DIFFERENCE

Tek might help to resolve a troubling issue that continues to baffle us. Although both the 8600A and the 7404 measured nearly identical total jitter on a 622-Mbps PRBS7 data stream (repeating pseudorandom binary sequence of length 2^7-1 bits), the two scopes' assessments of R_J and D_J (the random- and deterministic-jitter components) differed significantly (see **sidebar** "Jitter discrepancies: not explained"). We don't know which, if either, of the scopes made correct assessments. LeCroy has offered a plausible—albeit not necessarily correct—explanation of the 8600A's results (**Reference 2**). By press time, Tek had ignored several entreaties for comment on why company officials believe that the TDS 7404/JIT3 assessments are correct and that the 8600A/JTA2's are incorrect. Tek's silence is probably not a concession that its instrument produced incorrect results, and, should Tek offer a response, *EDN* will publish a link to it from our Web site.

Under our original plan, Tek was to bring a 6604 equipped with the JIT3 option. If *EDN* had been able to use such a scope for this test, the testers could have applied a 2.488-Gbps PRBS to both Tek and LeCroy scopes. However, the only Tek scope with the JIT3-analysis capabilities was the 7404. Its 4-GHz bandwidth

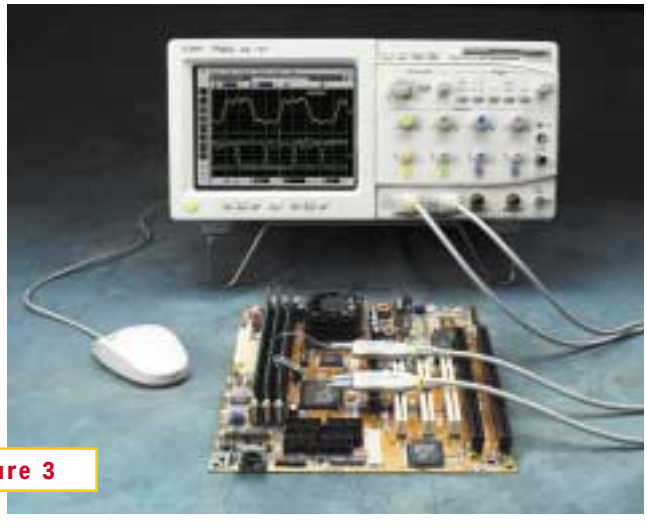
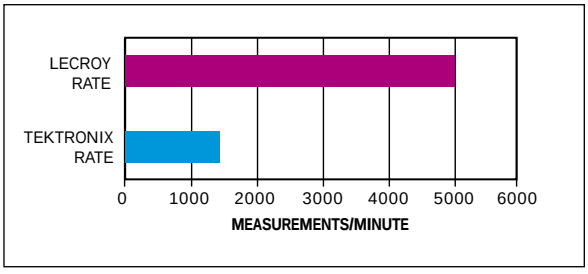


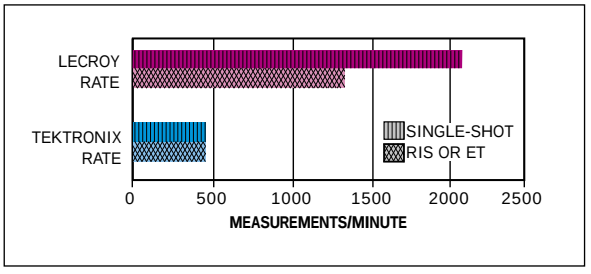
Figure 3

Agilent's Infiniium 54855A is the newest entrant in the four-channel, 6-GHz real-time-sampling field. It was unavailable for our shoot-out in late October 2002. Unlike its two competitors, which can sample faster than 10G samples/sec on only two channels at once, the 54855A can simultaneously sample four channels in real time at 20G samples/sec. Therefore, the scope can simultaneously capture without aliasing four signals that contain significant energy above 5 GHz.

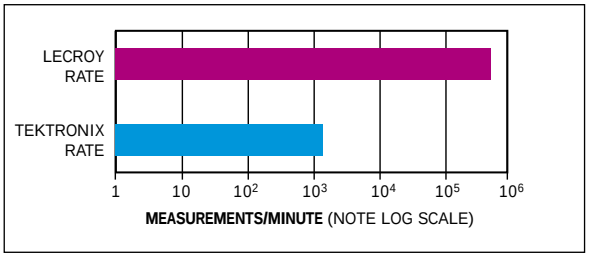
SUMMARY OF THROUGHPUT RESULTS



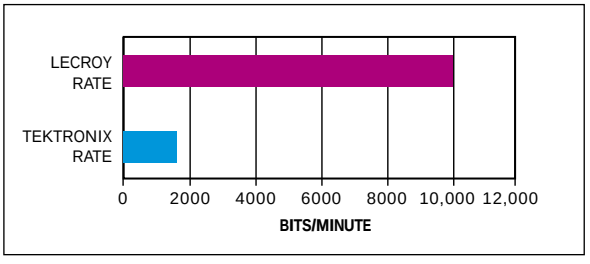
LECROY-PROPOSED TEST 1A: Simple 5.2-GHz sinusoid, with measurements of single-value-per-waveform, voltage-related parameters, such as peak-peak amplitude and rms value.
Throughput ratio: LeCroy/Tektronix=3.5.



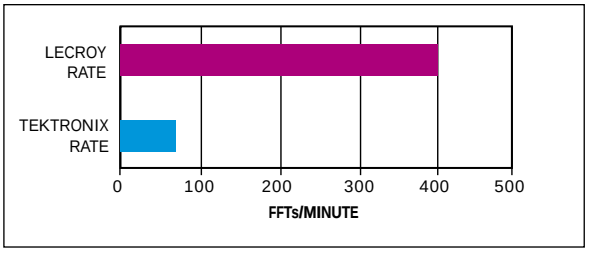
TEKTRONIX-PROPOSED TEST 1: Differential, fast-rise-time measurement using Agilent 8133A pulse generator and Picosecond Pulse Labs balun.
Throughput ratios: Single-shot (realtime) LeCroy/Tektronix=4.75
Random-interleaved sampling (equivalent time)
Throughput ratio: LeCroy/Tektronix=2.95.



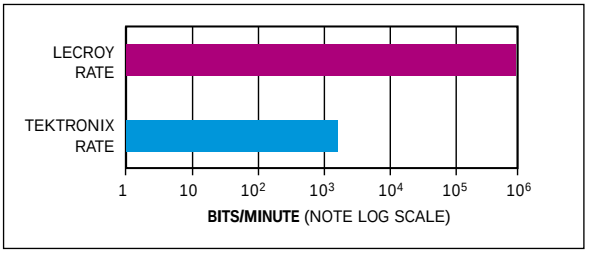
LECROY-PROPOSED TEST 1B: Same as above, but for multivalued, time-related parameters, such as period and frequency.
Throughput ratio: LeCroy/Tektronix=357.



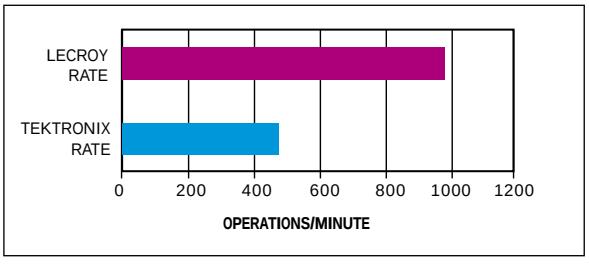
TEKTRONIX-PROPOSED TEST 2A: 2.5-Gbps eye diagram using LA Techniques LA19-01-01 data generator producing repetitive, pseudorandom-PRBS7-binary-sequence data stream.
Throughput ratio: LeCroy/Tektronix=6.5.



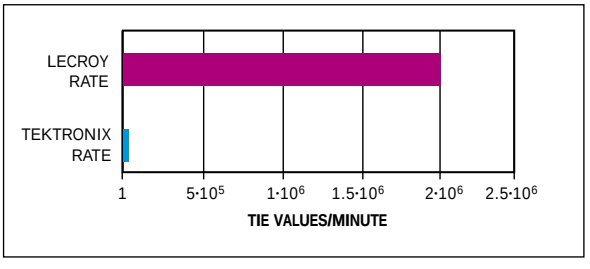
LECROY-PROPOSED TEST 2: Simple FFT measurement. (Note that we could not configure the TDS 6604 FFT record length to 100k samples.)
Throughput ratio: Lecroy/Tektronix=6.2.



TEKTRONIX-PROPOSED TEST 2B: 2.5-Gbps eye diagram using LA Techniques LA19-01-01 producing PRBS7 data stream, but on LeCroy scope, using SDM software option in mask-test mode.
Throughput ratio: LeCroy/Tektronix=651.



LECROY-PROPOSED TEST 3: Simple math and data logging or trending (Note that the Tektronix rate is quoted without actual trending, which would have required a connectivity solution.)
Throughput ratio: LeCroy/Tektronix=2.1.

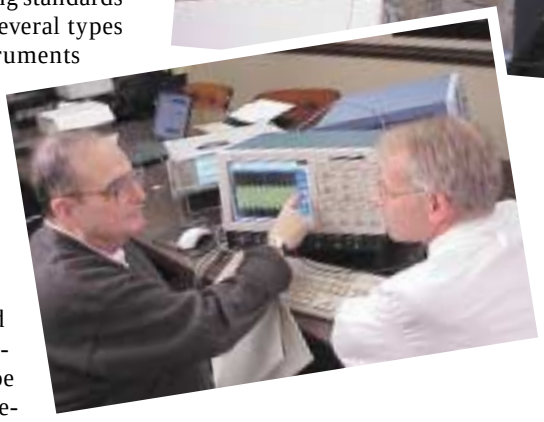


TEKTRONIX-PROPOSED TEST 4: Measurement of TIE (time-interval error) on a 622-Mbps data stream. (Note that we did not conduct test T3 because we ran out of time.)
Throughput ratio: LeCroy/Tektronix=70.

was, at best, marginal for the 2.488-Gbps stream, so the testers used a 622-Mbps stream and for consistency also applied this signal to the 8600A. It seems improbable that, with a 622-Mbps stream, the difference between the 7404's 4-GHz bandwidth and the 8600A's 6 GHz could account for the divergent R_J and D_J values.

One thing is certain, though: Jitter measurement is an immature science; some say that it remains an art. Many brilliant people are working in the field. Some of them are developing standards for measuring jitter, and several types of jitter-measurement instruments and software packages exist. If you work in design and your goal is to characterize and minimize jitter rather than quantify parameters, such as bit-error rate, which are mainly consequences of jitter—a good wideband scope with advanced analysis capabilities is likely to be your most valuable measurement tool. Even so, you may also want to use several other types of instrumentation.□

Figure 4



On the morning of Oct 29, 2002, the LeCroy representatives unpacked a carload of equipment and met with representatives from *EDN* and its sibling publication, *Test & Measurement World*, before the cry of "Gentlemen, start your oscilloscopes," resounded (from left, Michael Lauterbach, director of product management, LeCroy; Rick Nelson, executive editor, *Test & Measurement World*; Dan Strassberg, senior technical editor, *EDN*; and Martin T Miller, chief scientist, LeCroy). At left, Strassberg and Nelson examine the Tektronix TDS 6604.

References

1. Strassberg, Dan, "DSOs, probes simultaneously acquire four 6-GHz differential signals at 20G samples/sec," www.e-insite.net/ednmag/index.asp?layout=articlePrint&articleID=CA257061.

2. For detailed results of the shoot-out, see the HTML version of this article at www.edn.com.

Acknowledgment

As EDN*'s resident pundit, I must doff my hat to senior art director Mike O'Leary for coming up with this article's truly inspired headline.*

Author's biography

Dan Strassberg, who has covered test and measurement for EDN *for more than 15 years, holds a BSEE from Rensselaer Polytechnic Institute (Troy, NY) and an MSEE from Massachusetts Institute of Technology (Cambridge, MA). He has 30 years' experience in designing test-and-measurement products and managing engineering projects. As are most* EDN *readers, Strassberg is an aficionado of modern oscilloscopes because of their many capabilities and the indispensable roles they play in the work of so many EEs.*

FOR MORE INFORMATION...

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