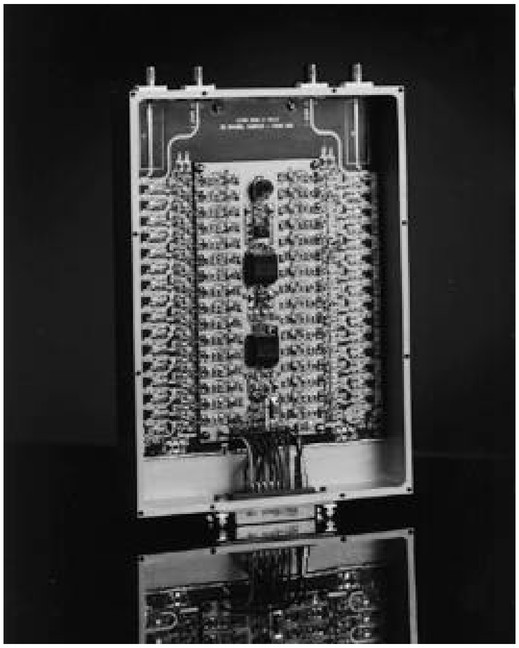
World's Fastest Solid-State Digitizer



Our solid-state transient digitizer, the world's fastest at capturing and recording an electrical event, advances the state of the art by nearly an order of magnitude through the use of a novel array of sampling diodes. This high-performance device is lower in manufacturing cost than competitive products, making it the new leader in the field of affordable, high-speed recorders.

THE ten-beam Nova laser at LLNL is the world's most powerful laser. Nova produces pulses that deliver up to 40 trillion watts (TW) of ultraviolet laser energy to a tiny spherical target in a billionth of a second. Since the laser's activation in 1984, we have developed increasingly sophisticated instruments to measure the interaction between the laser beams and the target plasma. In particular, to achieve high target compression, we must accurately measure the power of each of the beams to attain good power balance.

We normally measure the power of each beam with a photodiode that is read out by a high-speed oscilloscope. High-speed oscilloscopes have been available for several decades and contain a complicated vacuum cathode-ray tube with a precision deflection structure. The performance of high-speed oscilloscopes has improved over the years, but they remain rather complex, expensive to manufacture, and somewhat delicate. Even small gains in their performance would require considerable effort and cost.

In the late 1980s, researchers in the Inertial Confinement Fusion Program at the Laboratory began to develop a new digitizer for use on Nova and the next-generation laser now being planned. The instrument we developed to capture data generated with Nova and its successor has been dubbed the single-shot transient digitizer. Here, the word

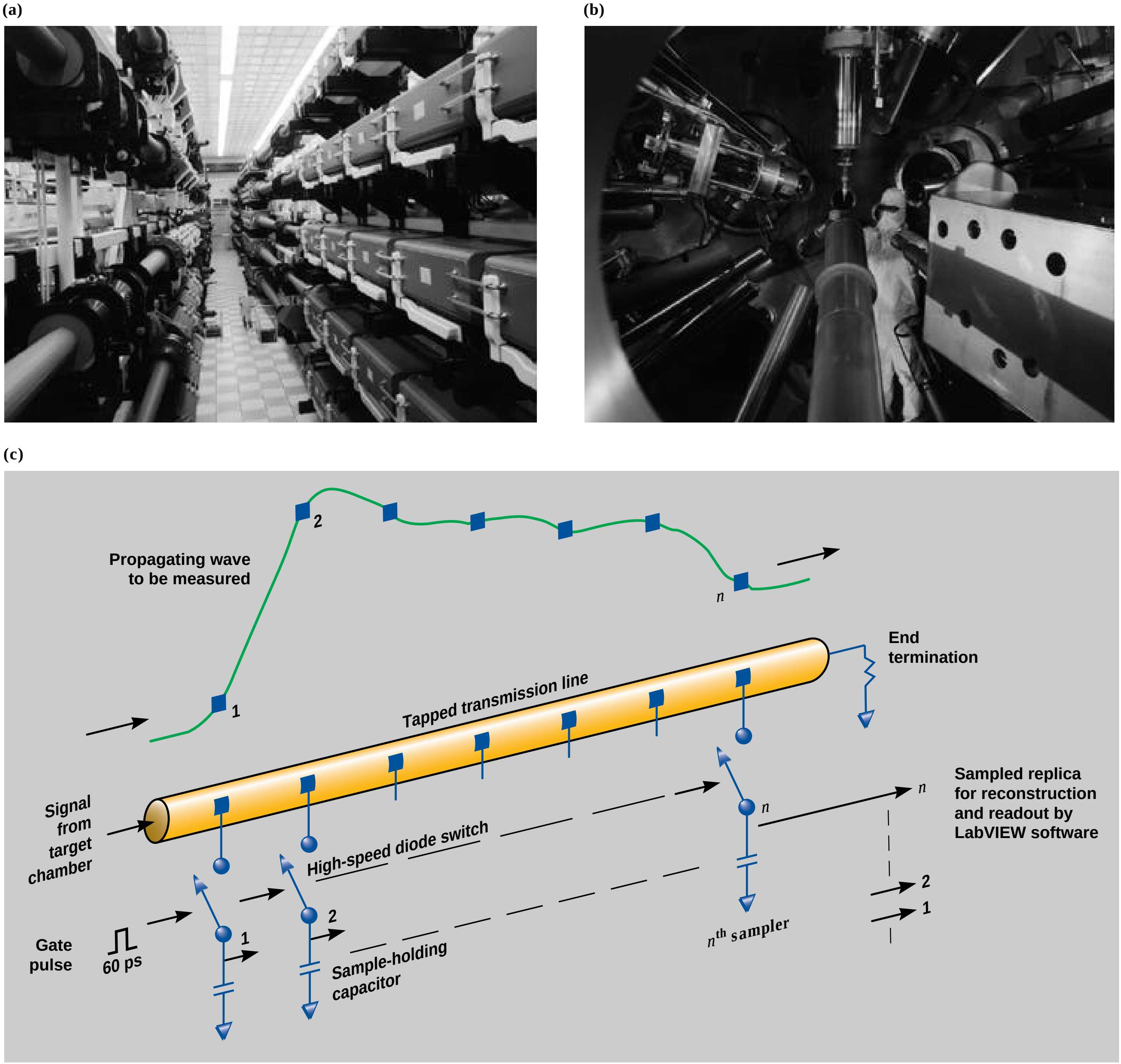


Figure 1. How the single-shot digitizer works in the current Nova application. The ten beams of the Nova laser (a) travel through the laser bay and then converge onto a small spherical target inside the target chamber (b). Photodiodes convert the light signal from the laser beam into an electric current. A propagating wave, shown schematically at the top of the simplified drawing (c), is the electrical signal we want to measure. The digitizer, which consists of an array of sample-and-hold circuits (samplers) tapped onto the transmission line, measures and records this electrical signal. When the digitizer receives a trigger, voltages at each tap—represented here as the small black squares—are sampled nearly simultaneously to form a replica of the signal waveform as it appears along the transmission line. The replica of the propagating waveform is stored on sample-and-hold capacitors for later readout at a slower rate.

"transient" refers to the very brief signal, or waveform, to be captured and recorded. "Single-shot" refers to the single electrical event that is recorded.

Although the idea behind the single-shot transient digitizer was first published in the early 1960s, several factors converged to spur the development of our practical and inexpensive version at LLNL in the 1980s. Most notable among these factors were advances taking place in high-speed pulse technology for our gating cameras, advances in the manufacturing of high-speed circuits, and our need for a large number of inexpensive recorders that could be used on Nova.

A future application for our solid-state transient digitizer will be on the 240-beam laser at the proposed National Ignition Facility. This next-generation laser will deliver fifty times more energy to the fusion target than Nova can deliver. Each of the 192 beams must be precisely measured to attain good power balance. Because of the large number of beams, we require instruments that are less costly than high-speed oscilloscopes.

How the New Transient Digitizer Works

The function of our transient digitizer is similar to that of a high-speed oscilloscope combined with a photographic camera or a digital-readout device. The digitizer records a single electrical event that lasts only 20 ns (1 ns = one billionth or 10^{-9} of a second).

To place the instrument in its current context, Figure 1a shows the Nova laser bay, and Figure 1b shows the interior of the Nova target chamber, where the ten beams converge. Photodiodes convert the light signals generated by Nova and by the target implosion into electric current. These electrical signals are the input pulses we can measure with the new digitizer.

The architecture of the digitizer is diagrammed in Figure 1c. The device consists of an array of electrical samplers located at various places, referred to as taps, along a transmission line within the digitizer. The transmission line carries the signal to be sampled. The taps in Figure 1c are indicated by the small black squares drawn at *n* locations on the propagating wave and the transmission line.

As an electrical signal moves along the transmission line, it is spread out along its length. When the digitizer is triggered, the periodically spaced samplers are all switched on briefly and nearly simultaneously to obtain a sampled replica, or "snapshot," of the waveform. The snapshot is stored on sample-holding capacitors for later readout by a high-resolution, analog-to-digital (A-to-D) converter.

The A-to-D converter stores the digital equivalent of the snapshot in computer memory for data processing. Our processing includes operations such as calibration and fitting an accurate, smooth curve to the samples. The smoothed curve closely represents the original signal waveform output and is displayed immediately after each acquisition on a computer monitor. The software code that handles these operations runs under the popular commercial package, LabVIEW. Figure 2 shows a typical output from our instrument, which compares well to that of a commercial high-speed oscilloscope costing substantially more than our instrument.

Even though the architecture of our instrument is fairly straightforward and was crudely implemented by others in the 1960s and 1970s, ours is the first high-speed version that can be easily built. While developing the device, we explored many ways to optimize its performance, flexibility, and ease of manufacturing while keeping cost low. The result is an instrument that won an R&D 100 award in 1993 (Figure 3).

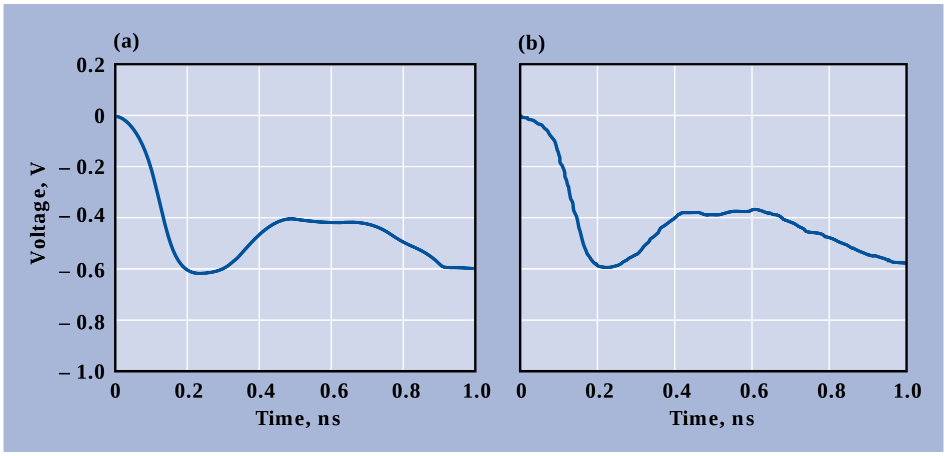


Figure 2. The response of the single-shot transient digitizer to a single pulse. This illustration shows that the output of our digitizer (a) is similar to that of the best commercial cathode-ray-tube-based digitizer (b).

Novel, High-Speed Samplers

Our greatest challenge in developing the new digitizer was to discover how to attach hundreds of samplers to a transmission line without affecting the quality of the signal to be measured. Each sampler must have minimal impact on the signal and must be switched with a common trigger or gate pulse. Each sampler must also have a very small number of components to hold down the cost and size of the instrument. After several years during which our ideas evolved, we chose the simplicity of one resistor and one dual-diode per sampler.

Figure 4 is an artist's concept of the resulting design. In this rendering, each straight line receding into the distance represents a gate pulse line that triggers the measurement. Each wavy line represents a transmission line carrying the signal to be sampled. The two triangles forming an hourglass-like structure represent a pair of diodes used for each sampler. The sampler circuit and array architecture containing the wavy transmission line, the straight gate pulse line, and the embedded sample-holding capacitor are unique LLNL developments with patents pending.

Our sampler is based on a pair of Schottky diodes that act as a high-speed switch. Schottky diode samplers first appeared in the 1960s and gave sampling oscilloscopes of the day bandwidths that extended to an astounding 12 GHz (a frequency equal to 12 billion hertz). Today, the figure has advanced to 50 GHz. The primary limitation to further increases in bandwidth lies not in the speed of Schottky diode samplers but in the availability of high-bandwidth coaxial connectors that are needed to bring the signal to the measuring instrument. (A 100-GHz connector is currently being developed by the electronics industry.)

Despite their exceedingly high bandwidth, sampling oscilloscopes are limited to taking only one sample per trigger and require repetitive triggers, or "looks," at the signal to build up an image. If a signal occurs only once, a sampling oscilloscope would provide only one sample point on the signal waveform, making the signal quite useless. In contrast, our new single-shot transient digitizer obtains a large number of samples from a single transient signal by using an array of samplers, as shown in Figure 4. The device is the first to organize Schottky diode samplers into a practical array that can harness their very large bandwidth.

Advantages Over Other Products

Competing oscilloscopes, such as the Tektronix SCD5000 manufactured in the U.S. or the Intertechnique IN7000 manufactured in France, are based on complex cathode-ray vacuum display tubes. These tubes

Figure 3. Tom McEwan (left) holds the single-shot transient digitizer, which won an R&D 100 award in late 1993. McEwan developed this device with Joseph Kilkenny (right) and with the help of electronics technician Gregory Dallum (center).

alone are very expensive and lead to a high retail price. In contrast, our new transient digitizer is entirely solid state and is built from low-cost, off-the-shelf components.

In addition to far lower cost, the single-shot transient digitizer is much smaller, more robust, and consumes less power than competitive products. Our instrument can also make more accurate measurements with a higher dynamic range. The maximum repetition rate of 5000 Hz is 1000 times faster than comparable oscilloscopes—an important consideration for impulse radar applications and component testing where high repetition rate is critical.

Current and Future Applications

Our immediate use for the single-shot transient digitizer is to replace the aging stock of high-speed oscilloscopes currently in place on Nova. We are initially building ten modules with 160 samplers each and anticipate completion in the summer of 1994. We are also combining into a single package the digitizer and a microcomputer for internal data processing and enhanced signal measurement.

The proposed next-generation laser—the National Ignition Facility—will require more than 300 digitizers with a time and amplitude resolution that cannot be met by any other digitizer in the world. We will use the new digitizers to monitor the power in each of the 192 laser beams and to measure the interaction of the laser light with the fusion target.

Two patents are pending on the single-shot transient digitizer, and we have shown the technology to major instrument manufacturers. We expect to license the technology for commercial manufacture during 1994.

Our single-shot digitizer can be modified to operate continuously at sampling rates of 33 billion samples per second or even higher. Digitizers that can acquire a very large number of samples—10,000 to 100,000—have a broad range of applications, including digital radiofrequency memory for electronic warfare; ultrahigh-resolution, long-range imaging radar; and a variety of data acquisition uses in computer manufacturing and telecommunications.

Other potential applications for our instrument include use in:

- Testing the effects of transient radiation doses.
- Recording information from pulsed accelerator diagnostics.
- Measuring fluorescence decay of materials.
- Testing high-speed digital chips used in computers.

We are pursuing many applications, but one is especially promising. Our digitizer can be used as a receiver for radars that emit and detect very short electromagnetic impulses to form high-resolution images of targets. These radars are known as ultrawideband impulse

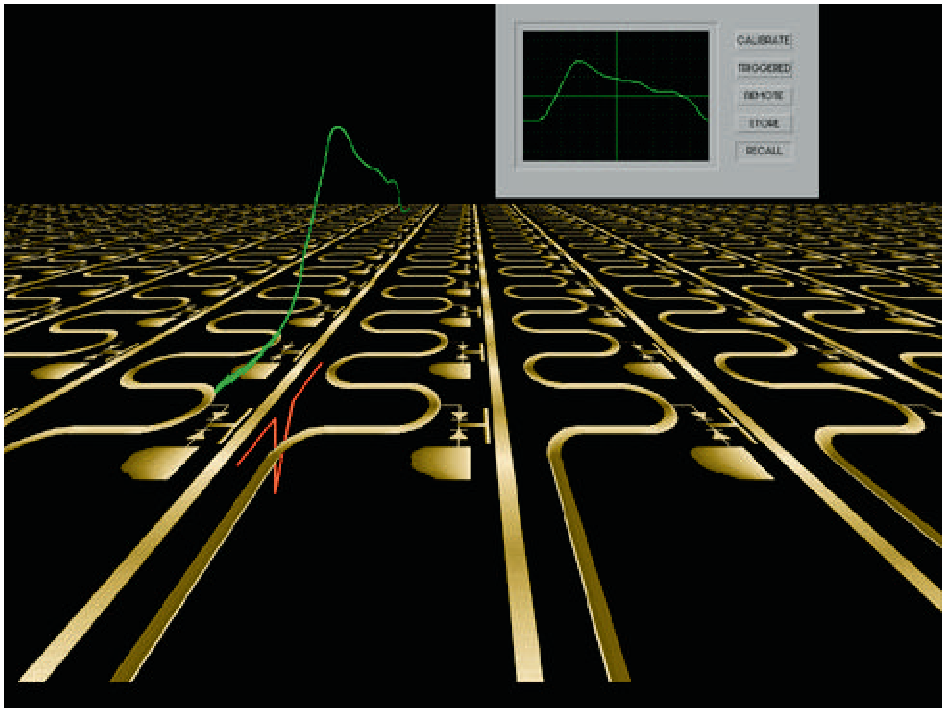


Figure 4. Artist's concept of the unique design of our sampler circuit. In this rendering, each straight line receding into the distance is a gate pulse line that triggers the measurement. Each wavy line represents a transmission line carrying the signal to be sampled. An example of one signal is shown above a transmission line and also on the computer monitor. The two triangles forming an hourglass-like structure represent the pair of Schottky diodes that function as a high-speed switch for each sampler. Sample-holding capacitors to store information are located just below each pair of diodes. By incorporating hundreds of samplers into this unique, yet extremely simple design, we can obtain a detailed snapshot of a single transient signal—something no sampling oscilloscope can do.

radars, and they are particularly useful in penetrating soil and concrete. Commercially available impulse radars are used to locate archeological artifacts and to examine the internal structure of highway bridges.

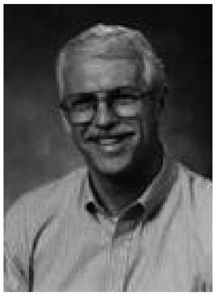
To form an image, however, impulse radars must either repetitively sample the echoes with a single sampler, which is time consuming, or they must use an expensive high-speed oscilloscope to obtain a complete echo waveform from each pulse transmission. Our digitizer can be used as a compact, low-cost receiver for complete echo acquisition. It allows faster image formation with less noise corruption than is possible with high-speed oscilloscopes. We expect to see our digitizer in these applications after it is commercialized.

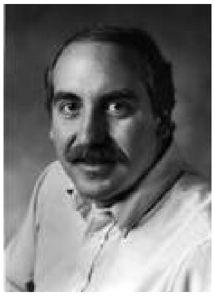
On another front, we plan to use the digitizer as a receiver for an airborne impulse radar that will record images of ocean waves. This work is part of an ongoing LLNL effort in environmental research.

Summary

The single-shot transient digitizer is a significant advance in digitizer technology. Using only low-cost, off-the-shelf components, we have produced a product that is eight times faster than comparable solid-state devices, and one that is lower in manufacturing cost than high-speed, cathode-ray-tube-based digitizers now on the market. Other advantages include larger dynamic range, substantially smaller size, and ease of manufacturing. The unique structure of our device provides a new way to harness the speed of diode samplers. High performance, low cost, and a wide range of potential applications make the instrument the new leader in high-speed transient digitizers.

Key Words: cathode-ray-tube; computer code—LabVIEW; high-speed oscilloscope; impulse radars; National Ignition Facility; Nova laser; R&D 100 award; Schottky diode; single-shot transient digitizer.





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