UCLA researchers first to capture elusive lightning-quick waveforms

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Discovery could help scientists develop defenses against high-powered e-bombs and allow physicists to view fundamental building blocks of nature

Researchers at UCLA have for the first time been able to capture and digitize electrical signals at the rate of 1 trillion times per second, a discovery that eventually may help scientists develop defenses against high-powered microwave weapons attacks and allow physicists to peer into the fundamental building blocks of nature.

Professor Bahram Jalali and graduate researcher Yan Han at UCLA's Henry Samueli School of Engineering and Applied Science have developed a revolutionary one tera sample per second single-shot digitizer that will allow scientists to see, analyze and understand lightning-quick pulses. The team's breakthrough is being announced March 23 at the 2005 American Physical Society's March meeting at the Los Angeles Convention Center.

"As electronic devices become smaller and faster, they also become more susceptible to outside interference," Jalali said. "In order to make equipment more robust, to shield it from electromagnetic attacks, you first have to understand what kind of signals you're dealing with. Because the pulses we're talking about are one-time events and are extremely fast, their capture and analysis eludes conventional digitizers. That's exactly what our technique allows."

The discovery has important ramifications. Measurement of electrical waveforms is needed in virtually every field of engineering and science. All signals, whether generated by nature or in experiments, are analog. In order for a computer to process and ultimately analyze these signals, they first must be digitized. Despite recent advances, traditional analog-to-digital converters are still not fast enough to capture these lightning-quick waveforms.

The approach taken by other researchers and one that has not advanced in recent years has focused on making the digitizer faster. The key to UCLA's success in capturing these signals is, ironically, to slow them down. This provides a quantum leap in performance.

The one-tera-sample-per-second single-shot digitizer captures lightning-quick waveforms 50 times faster than the best commercially available digitizer. Using light to slow down the electrical waveforms, these ultra-fast waveforms can be digitized at pico-second intervals – or one-millionth of one-millionth of a second. The achievement is the culmination of eight years of research, funded by the Defense Advanced Research Project Agency (DARPA).

One application being studied is the development of defenses against the microwave "e bomb." The concept behind such high-powered weapons is simple. A burst of electromagnetic energy is created and directed at an electronics system. The resulting ultra-fast burst of charge burns them out -- much like lightning can destroy objects in its path. In a computer-dependent society, a weapon that renders communications devices useless could be devastating. Such a weapon theoretically could damage computer networks and destroy wireless communication equipment and radar systems.

To capture these pulses, the team at UCLA uses a novel optical time-dilation processor followed by a conventional electronic digitizer. The time-dilator takes the ultra-fast event and slows it down so it can be caught by the digitizer. Although the processor's input and output are electrical, the actual time manipulation is done in the optical domain.

"Imagine you have a flat rubber band and you draw an arrow on it. The arrow's length reflects the duration of the event. When you stretch the rubber band, the arrow is elongated, meaning that the event now occurs over a longer time -- in other words, the event is slowed down in time," Jalali said. "With our technique, a laser pulse is the rubber band. An optical modulator writes the ultra-fast waveform onto the optical pulse. The composite signal is then slowed down in a dispersive optical device, such as a chain of optical resonators made on a silicon chip. A photo detector then converts everything to the electrical domain and gives a slowed-down copy of the original electrical waveform."

The team at UCLA also has shown that the resulting time-elasticity can be used to perform time compression and time reversal, capabilities that have application in advanced radar systems.

UCLA's approach has other significant ramifications for areas of research such as particle physics, among others. The technique also will allow physicists to capture the smashing of particles, and by analyzing that instant, peer into the very fundamental building blocks of nature on the smallest scale.

RadiaBeam Technologies LLC of Los Angeles already has entered into licensing negotiations with UCLA for the patents that led to the breakthrough. The company plans to commercialize the technology and produce a laboratory tool for high-energy physics research, said Salime Boucher, president of RadiaBeam.

"We see a market for this breakthrough with research laboratories involved in ultra-fast phenomena and transient events, as well as for future applications by engineering and technology companies in the communication, chemical engineering and life science sectors," Boucher said.

A research prototype already is in development for space applications.

"Direct digitization of signals in the 10 to 100 GHz band and beyond offers incredible opportunities for new applications in communications, spectroscopy and radar," said George C. Valley, senior scientist at the Aerospace Corporation, the company researching the time stretch ADC for potential space applications. "Besides breaking the tera-sample-per-second rate barrier, the results reported by Jalali's group at UCLA beat other photonic analog-to-digital converter technologies by about a factor of 10 in the key figure of merit, bit rate times number of quantization levels."

The digitizer consists of an optical time-dilation processor followed by an electronic digitizer. All the necessary optical components, including pulsed lasers, optical modulators, amplifiers and dispersive elements have already been made using silicon. The recent advances in silicon photonics make it possible to integrate the entire digitizer on a silicon chip, leading to a compact and low-cost solution.

Source: University of California - Los Angeles

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