Got Solitons? Researcher sees problem as a solution

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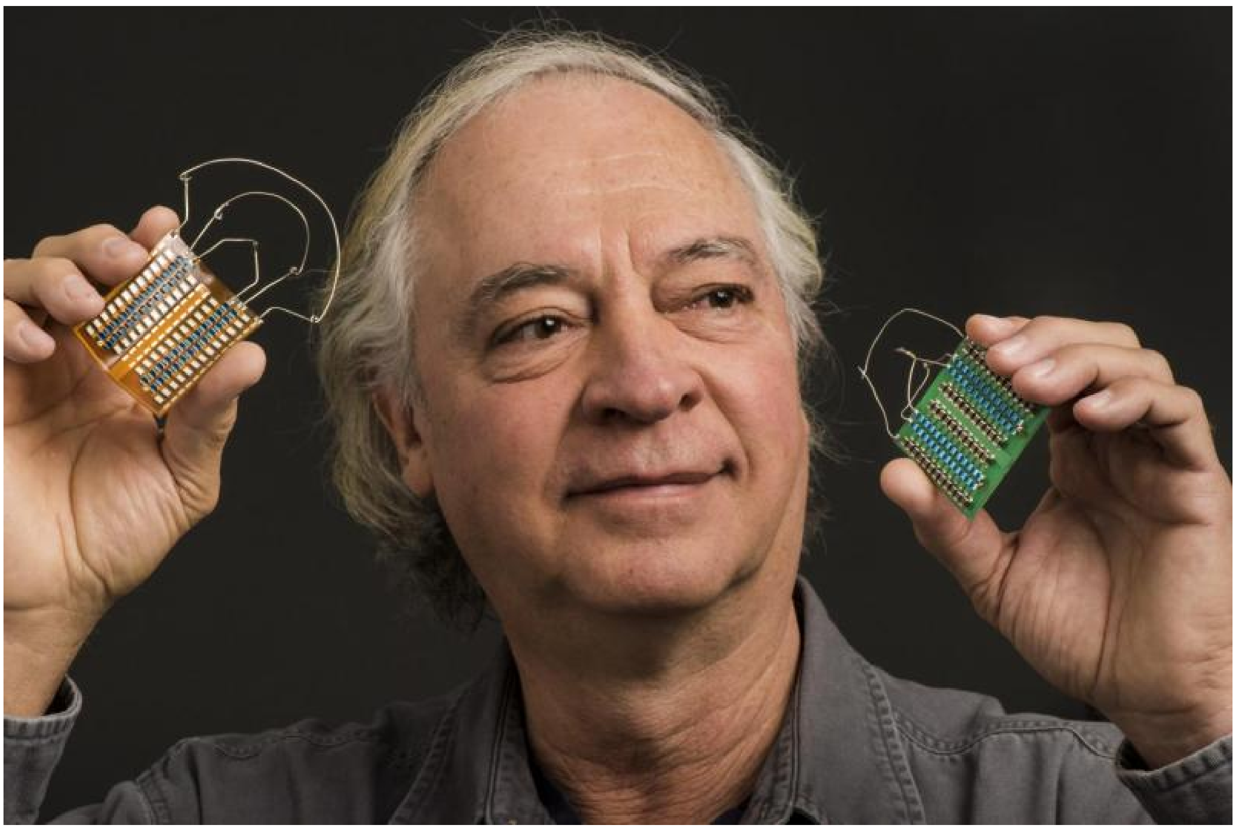

Sandia National Laboratories researcher Juan Elizondo-Decanini holds two compact, high-voltage nonlinear transmission lines. Elizondo-Decanini leads a project on nonlinear behavior in materials — behavior that's usually shunned because it's so unpredictable. Credit: Randy Montoya

Sandia National Laboratories' Juan Elizondo-Decanini turned a longstanding problem into an idea he believes could lead to better and less expensive machines, from cell phones to pressure sensors.

"This is one of those cases where it appears it's going to result in substantial savings and it's going to generate a whole suite of new gadgets," he said.

Elizondo-Decanini leads a project on nonlinear behavior in materials—behavior that's usually shunned as too unpredictable. Instead of avoiding nonlinearity, Elizondo-Decanini is embracing it by using harmonic waves called solitons and studying, for example, how nonlinearity might be used in capacitors to further improve cell phone reception or lock out computer hackers.

Capacitors are fundamental elements in electronic circuits that store energy by accumulating electrical charge after voltage is applied to them. The stored charge is determined by the capacitance value: the more capacitance, the more charge stored and the more energy at a given "charge" voltage. High-quality capacitors are considered linear because capacitance value doesn't change as voltage is applied to store a charge. In a nonlinear capacitor, capacitance value changes as voltage is applied, so the energy or stored charge is different from what was expected.

In other words, there's no direct linear relationship between what's applied as an input and what's measured as the output in nonlinear behavior. For example, a liter of water remains a liter if it simmers below the boiling point, a linear behavior. But imagine if water could behave in a nonlinear manner, where a liter might expand to 5 liters when simmered.

"People try to stay away from nonlinear behavior because they want everything to be very simply predictable," Elizondo-Decanini said. "When it's linear you need to put as much effort into it as you get out of it. When it's nonlinear, sometimes you put in a little bit of effort and it just takes off. In a nonlinear circuit, as energy is conserved, you may change or amplify the voltage at the expense of the current or the other way around, depending on the nonlinear component."

Nonlinear concept receives patent

Sandia received U.S. patent 8,922,973 this year for "a detonator comprising a nonlinear transmission line" developed by Elizondo-Decanini. The patent describes using a nonlinear feature to obtain very high voltages. Elizondo-Decanini and collaborators have since filed technical advances for other applications. A technical advance is a very preliminary draft of a patent application that discloses the technical idea by the inventors to patent attorneys, who use it to create a patent application.

Nonlinear behavior would seem undesirable in detonators, where safety is paramount. The main safety feature in a detonator is a driver circuit and switch that prevent accidental activation. Detonator drivers use high-quality linear capacitors to ensure exact current so the detonator works only when the switch is flipped.

However, high-quality capacitors are expensive due to the huge research investments needed to explore linear materials and the sophisticated designs those materials require, Elizondo-Decanini said. So he turned the problem on its head: "What if we can use the worst characteristic of capacitor material, being nonlinear, to our advantage?"

His team focused on electrical solitons for a high-resistance detonator made with cheap capacitors. Solitons, used in laser and fiber optic communication, are harmonic waves that travel long distances without losing shape. They can be generated with nonlinear materials arranged as a transmission line; hence the patent's name.

"Solitons like nonlinear material. The advantage is that if one manipulates the transmission line timing, the pulse width is compressed, resulting in amplified voltage," Elizondo-Decanini said. "Instead of putting in 300 volts to get out 300 volts, perhaps you put in 100 and get out 1,000. So far the team has demonstrated as much as 75 kilovolts from a 7-kilovolt input pulse."

Initially, to test solitons for nonlinear transmission lines, the team used nonlinear capacitors, which are so roundly hated many companies don't even make them anymore. Elizondo-Decanini obtained cheap, out-of-production capacitors that behaved so nonlinearly they were used only in devices where linear behavior isn't important, such as starter motors.

Working with other research projects on potential applications

Elizondo-Decanini's Laboratory Directed Research and Development (LDRD) project is now testing the concept in experiments with other Sandia research groups.

One project examines ultra-wide bandgap materials. "If this approach is successful, it is a revolutionary use of nonlinear transmission line circuit topologies with solid-state capacitors based on ultra-wide bandgap for many applications," Elizondo-Decanini said.

For example, it might extend cell phone range. When a cell phone starts to lose reception, it shifts frequency a little to lock into a stronger signal. "Sometimes you hear noise and then it comes back and it locks again. What this does is enhance that locking a little bit, so that eventually you will not hear that drift," Elizondo-Decanini said.

The ultra-wide bandgap project, headed by researcher Bob Kaplar, came into the mix because of the diodes Kaplar's team is investigating. They consist of negative and positive material, with neutral material in between that forms a capacitor—and also has unwelcome nonlinearity.

In addition to the normal positive-to-negative flow, diodes can be used with a negative-to-positive or reversed bias, which takes advantage of their nonlinear capacitance. This is possible because as the applied reversed voltage is increased, such as with a voltage pulse applied to a transmission line, the negative and positive semiconductor materials respond by abruptly reducing the size of the neutral region between them. That dramatically amplifies the voltage as it travels through the line. Elizondo-Decanini said that if Kaplar's team can design diodes with very high reversed bias voltage, it opens the possibility of replacing high voltage capacitors with diodes, taking full advantage of the nonlinearity.

"A high voltage ultra-wide bandgap-based nonlinear transmission line is a revolutionary approach that can replace magnetic-core-based, high-voltage pulsed transformers such as automotive coil packs, among other things," he said.

Collaborating research could lead to new gadgets

Kaplar said Elizondo-Decanini's potential application is one of two demonstration projects within his larger project. "It's a cool thing," he said. "It's not your traditional application, but it so happens the things we're doing are very well-suited for his work. It's basically making use of the properties of the semiconductor to do some of the things he wants.

"In theory, by changing the design and growth of the device, you could get a particular capacitance versus voltage curve that you want," Kaplar said. "That's where wide bandgap and ultra-wide bandgap are good."

In another collaboration, Elizondo-Decanini and colleagues filed a technical advance for pressure sensors for vacuums that would sense very small variations in pressure by using nonlinear capacitor behavior coupled with concepts developed by an LDRD project on micro-discharge plasma. "By combining those two with an oscillator, we can measure pressure in a way that's never been done before," Elizondo-Decanini said. "It may be more sensitive, it will be miniature and it can be embedded inside devices."

Microsensor researchers Ron Manginell and Matt Moorman are working with Elizondo-Decanini because his theory is an extension of their work to reduce large-scale plasmas to micron-size dimensions. "In plasmas, if you increase the pressure to atmospheric pressure you can decrease the size," Manginell said. "The scaling works in your favor and you can build really tiny plasma devices."

Microplasma devices produce intense light spanning the range from deep ultraviolet through the visible spectrum and into the infrared. Their excellent light emission is useful for applications in atomic, chemical and solid-state physics. That includes light-induced modulation of diodes near each other in which light emission from the microplasma shining on a diode generates electrical charges in it—akin to common roof-top solar panels in which sunlight creates charges in a solar cell diode to use for household electricity. Similarly, light from the microplasma generates charges in an adjacent diode, changing its capacitance, Manginell said. Since the diode has a nonlinear capacitance, it's a way to create a nonlinear capacitance change, he said.

Another technical advance was filed for encryption that would take advantage of nonlinearity in analog hardware as a physical barrier against hacking. Elizondo-Decanini said the concept needs more work, but the idea is that a user punches in a code that generates a unique electrical signal to unlock the computer, phone or other device.

"It's not a code, it's not digital, it's a signal," he said. "That makes a difference for security." Hackers can't get in without the device itself because unlocking it is linked to a circuit on a chip inside. "Even if they have your password, as long as they don't punch it on your phone, it's useless. From the outside, nobody can hack into it from the phone line, from the Internet, whatever."

Potential uses arose as his team developed nonlinear behaviors in materials, "and we started combining that with other technologies developing around Sandia," Elizondo-Decanini said. "All of a sudden we're creating new devices together."

Provided by Sandia National Laboratories