from laser diodes that are located away from the crystal to aid in dissipating the heat generated in the diodes and their drive circuits. The output of the Nd:YVO_4 crystal has a wavelength of 1064 nm, and is made to pass through frequency-doubling and frequency-tripling crystals. As a result, the net laser output is a collinear superposition of beams at wavelengths of 1064, 532, and 355 nm.

The laser operates at a pulse-repetition rate of 5 kHz, emitting per-pulse energies of 50 μJ at 1064 nm, 25 μJ at 532 nm, and 50 μJ at 355 nm. The transmitted laser beam and the returning laser light backscattered from atmospheric aerosols and molecules pass through a telescope, the primary optical element of which is an off-axis parabolic mirror having an aperture diameter of 20 cm. The combination of the off-axis arrangement and other features is such that none of the transmitting aperture is obscured and only about 20 percent of the receiving aperture is obscured.

The returning light collected by the telescope is separated into wavelength components by use of dichroics and narrowband interference filters suppress solar background. The 1064-nm signal is further separated into parallel and perpendicular polarization components. A half-wave plate is inserted in the 1064-nm path to enable calibration of the parallel- and perpendicular-polarization channels. Each resulting output wavelength component is coupled via an optical fiber to a photodetector.

An important feature of this system is an integrating sphere located between the laser output and the laser beam expander lenses. The integrating sphere collects light scattered from the lenses. Three energy-monitor detectors are located at ports inside the integrating sphere. Each of these detectors is equipped with filters such that the laser output energy is measured independently for each wavelength. The laser output energy is measured on each pulse to enable the most accurate calibration possible.

The 1064-nm and 532-nm photodetectors are, more specifically, single-photon-counting modules (SPCMs). When used at 1064 nm, these detectors have approximately 3 percent quantum efficiency and low thermal noise (fewer than 200 counts per second). When used at 532 nm, the SPCMs have quantum efficiency of about 60 percent. The photodetector for the 355-nm channel is a photon-counting photomultiplier tube having a quantum efficiency of about 20 percent.

The use of photon-counting detectors is made feasible by the low laser pulse energy. The main advantage of photon-counting (in contradistinction to processing of analog photodetector outputs) is ease of inversion of data without need for complicated calibration schemes like those necessary for analog detectors. The disadvantage of photon-counting detectors is that they inherently have narrow dynamic ranges. However, by using photon-counting detectors along with a high-repetition-rate laser, it is possible to obtain wide dynamic range through accumulation of counts over many pulses.

This work was done by Matthew McGill and V. Stanley Scott of Goddard Space Flight Center, Luis Ramos Izquierdo of LRI Corp., and Joe Marzouk of Sigma Space Corp. Further information is contained in a TSP (see page 1). GSC-14985-1

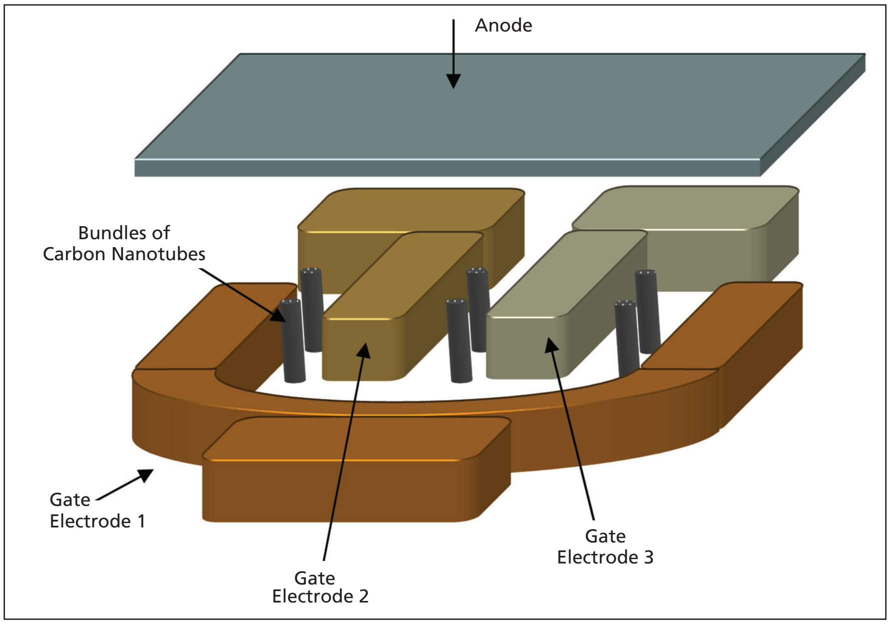
Radiation-Insensitive Inverse Majority Gates

These gates would be implemented as microscopic vacuum electronic devices.

NASA's Jet Propulsion Laboratory, Pasadena, California

To help satisfy a need for high-density logic circuits insensitive to radiation, it has been proposed to realize inverse majority gates as microscopic vacuum electronic devices. In comparison with solid-state electronic devices ordinarily used in logic circuits, vacuum electronic devices are inherently much less adversely affected by radiation and extreme temperatures.

The proposed development would involve state-of-the-art micromachining and recent advances in the fabrication of carbon-nanotube-based field emitters. A representative three-input inverse majority gate (see figure) would be a monolithic, integrated structure that would include three gate electrodes, six bundles of carbon nanotubes (serving as electron emitters) at suitable positions between the gate electrodes, and an overhanging anode. The bundles of carbon nanotubes would be grown on degenerately doped silicon substrates that would be parts of the monolithic structure. The gate electrodes would be fabricated



A **Three-Input Inverse Majority Gate** as proposed would be a microscopic vacuum electronic device containing bundles of carbon nanotubes positioned between gate electrodes to obtain controlled field emission of electrons from the bundles. In the presence of a fixed positive bias potential on the anode, the application of suitable (possibly smaller) bias potential to any two or all three gate electrodes would divert all the electron current from the anode.

as parts of the monolithic structure by means of a double-silicon-on-insulator process developed at NASA's Jet Propulsion Laboratory. The tops of the bundles of carbon nanotubes would lie below the plane of the tops of the gate electrodes. The particular choice of shapes, dimensions, and relative positions of the electrodes and bundles of carbon nanotubes would provide for both field emission of electrons from the bundles of carbon nanotubes and control of the electron current to obtain the inverse majority function, as described next.

The application of a positive bias potential to the anode would cause emission of electrons from the bundles of carbon nanotubes and, if no bias potential were applied to the gate electrodes, the electrons would travel to the anode, giving rise to an anode current. Relative to the anode, the gate electrodes would be much closer to the bundles of carbon nanotubes, such that the application of a smaller positive bias potential to a gate electrode would suffice to divert, to that electrode, the electrons emitted by the adjacent bundles of carbon nanotubes.

If the positive bias potential were not applied to another gate electrode, then the anode would continue to draw an electron current from the bundles of carbon nanotubes not adjacent to the positively biased gate electrode. However, if the positive bias potential were applied to any two or all three of the gate electrodes, then all of the electrons emitted by all the bundles of carbon nanotubes would be diverted to the positively biased gate electrodes, causing the anode current to fall to zero. In terms of binary logic, if one regards nonzero anode current as representing output state 1, zero anode current as representing output state 0, positive gate-electrode bias as representing input state 1, and zero gate-electrode bias as representing input state 0, then logical 0 inputs to two or all three of gate terminals would result in output of logical 1, and logical 1 inputs to two or all three of the gate terminals would result in output of logical 0. This relationship among input and output states constitutes a NAND and a NOR gate combination. This is the inverse majority function.

This work was done by Harish Manohara and Mohammad Mojarradi of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-45388 volume and number of this NASA Tech Briefs *issue, and the page number.*

Reduced-Order Kalman Filtering for Processing Relative Measurements

A Kalman filter can be propagated using fewer computations.

NASA's Jet Propulsion Laboratory, Pasadena, California

A study in Kalman-filter theory has led to a method of processing relative measurements to estimate the current state of a physical system, using less computation than has previously been thought necessary. As used here, "relative measurements" signifies measurements that yield information on the relationship between a later and an earlier state of the system. An important example of relative measurements arises in computer vision: Information on relative motion is extracted by comparing images taken at two different times.

Relative measurements do not directly fit into standard Kalman filter theory, in which measurements are restricted to those indicative of only the current state of the system. One approach heretofore followed in utilizing relative measurements in Kalman filtering, denoted state augmentation, involves augmenting the state of the system at the earlier of two time instants and then propagating the state to the later time instant. While state augmentation is conceptually simple, it can also be computationally prohibitive because it doubles the number of states in the Kalman filter.

In many practical applications, relative measurements are not functions of entire earlier states but rather may be a function of only a subset of elements of the earlier state. A relative measurement that can be thus characterized is denoted a partial relative measurement. For example, in computer vision, relative-measurement information is usually a function of position rather than velocity, acceleration, or other elements of the state.

When processing a relative measurement, if one were to follow the state-augmentation approach as practiced heretofore, one would find it necessary to propagate the full augmented state Kalman filter from the earlier time to the later time and then select out the reduced-order components. The main result of the study reported here is proof of a property called reduced-order equivalence (ROE). The main consequence of ROE is that it is not necessary to augment with the full state, but, rather, only the portion of the state that is explicitly used in the partial relative measurement. In other words, it suffices to select the reduced-order components first and then propagate the partial augmented state Kalman filter from the earlier time to the later time; the amount of computation needed to do this can be substantially less than that needed for propagating the full augmented Kalman state filter.

This work was done by David S. Bayard of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-44427