Because there is a need to move the resonant frequency of oscillators to the order of gigahertz, new technologies and materials are being investigated that will make performance at those frequencies attainable. By moving to nanoscale structures, in this case vertically oriented, cantilevered carbon nanotubes (CNTs), that have larger aspect ratios (length / thickness) and extremely high elastic moduli, it is possible to overcome the two disadvantages of both bulk acoustic wave (BAW) and surface acoustic wave (SAW) resonators.

Nano-electro-mechanical systems (NEMS) that utilize high aspect ratio nanomaterials exhibiting high elastic moduli (e.g., carbon-based nanomaterials) benefit from high Qs, operate at high frequency, and have small force constants that translate to high responsivity that results in improved sensitivity, lower power consumption, and improved tunablity. NEMS resonators have recently been demonstrated using top-down, lithographically fabricated approaches to form cantilever or bridge-type structures. Top-down approaches, however, rely on complicated and expensive e-beam lithography, and often require a release mechanism. Resonance effects in structures synthesized using bottom-up approaches have also recently been reported based on carbon nanotubes, but such approaches have relied on a planar two-dimensional (2D) geometry. In this innovation, vertically aligned tubes synthesized using a bottom-up approach have been considered, where the vertical orientation of the tubes has the potential to increase integration density even further.

The simulation of a vertically oriented, cantilevered carbon nanotube was performed using COMSOL Multiphysics, a finite element simulation package. All simulations were performed in a 2D geometry that provided consistent results and minimized computational complexity. The simulations assumed a vertically oriented, cantilevered nanotube of uniform density (1.5 g / cm^3). An elastic modulus was assumed to be 600 GPa, relative permittivity of the nanotube was assumed to be 5.0, and Poisson's ratio was assumed to be 0.2. It should be noted that the relative permittivity and Poisson's ratio for the nanotubes of interest are not known accurately. However, as in previous simulations, the relative permittivity and Poisson's ratios were treated as weak variables in the simulation, and no significant changes were recognized when these variables were varied.

Of interest in the simulations of a CNT resonator were the structural strain and deflection of the nanotube, and the electrostatic interactions between the nanotube and nanomanipulator probe. Structural boundary conditions were arranged such that the exposed lengths and tip of the nanotube were allowed to move freely while all other surfaces were held fixed (including the nanotube base). These conditions simulated a fixed, cantilevered beam in a domain adjacent to a nanomanipulator probe of infinite elastic modulus. Electrostatic boundary conditions were chosen such that the nanotube was grounded, an AC voltage with DC bias was applied to the surface of the nanoprobe adjacent to the nanotube, and all other boundaries in the system were selected such that no electrical charge exists on, or outside of, those surfaces. The solution domain was simulated as a vacuum. Preliminary experiments have suggested that electromechanical coupling can occur between a scanning electron microscope (SEM) beam and a vertically oriented, cantilever carbon nanofiber (CNF) causing the CNF to mechanically resonate with displacements two or three times larger than the tube diameters.

This work was done by Anupama B. Kaul and Larry W. Epp of Caltech and Leif Bagge of the University of Texas for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov.

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:

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Refer to NPO-47238 , volume and number of this NASA Tech Briefs *issue, and the page number.*

Ultracapacitor-Based Uninterrupted Power Supply System

This technology provides essential backup power, increases safety, and reduces environmental impact.

John H. Glenn Research Center, Cleveland, Ohio

The ultracapacitor-based uninterrupted power supply (UPS) system enhances system reliability; reduces life-of-system, maintenance, and downtime costs; and greatly reduces environmental impact when compared to conventional UPS energy storage systems. This design provides power when required and absorbs power when required to smooth the system load and also has excellent low-temperature performance. The UPS used during hardware tests at Glenn is an efficient, compact, maintenance-free, rack-mount, pure sine-wave inverter unit.

The UPS provides a continuous output power up to 1,700 W with a surge rating of 1,870 W for up to one minute at a nominal output voltage of 115 VAC. The ultracapacitor energy storage system tested in conjunction with the UPS is rated at 5.8 F. This is a bank of ten symmetric ultracapacitor modules.

Each module is actively balanced using a linear voltage balancing technique in which the cell-to-cell leakage is dependent upon the imbalance of the individual cells. The ultracapacitors are charged by a DC power supply, which can provide up to 300 VDC at 4 A. A constant-voltage, constant-current power supply was selected for this application. The long life of ultracapacitors greatly enhances system reliability, which is significant in critical applications such as medical power systems and space power systems. The energy storage system can usually last longer than the application, given its 20-year life span. This means that the ultracapacitors will probably never need to be replaced and disposed of, whereas batteries require frequent replacement and disposal. The charge-discharge efficiency of rechargeable batteries is approximately 50 percent, and after some hundreds of charges and discharges, they must be replaced. The charge-discharge efficiency of ultracapacitors exceeds 90 percent, and can accept more than a million charges and discharges. Thus, there is a significant energy savings through the efficiency improvement, and there is far less downtime for applications and labor involved in replacing an ultracapacitor versus batteries. Also, the lengthy lifespan of this design would greatly reduce the disposal problems posed by lead acid, nickel cadmium, lithium, and nickel metal hydride batteries.

This innovation is recyclable by nature, which further reduces system costs. The disposal of ultracapacitors is simple, as they are constructed of non-hazardous components. They are also safer than batteries in that they can be easily discharged, and left indefinitely in a safe, discharged state where batteries cannot.

This work was done by Dennis J. Eichenberg for Glenn Research Center. Further information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steven Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18649-1.

Coaxial Cables for Martian Extreme Temperature Environments

NASA's Jet Propulsion Laboratory, Pasadena, California

Work was conducted to validate the use of the rover external flexible coaxial cabling for space under the extreme environments to be encountered during the Mars Science Laboratory (MSL) mission. The antennas must survive all ground operations plus the nominal 670-Martian-day mission that includes summer and winter seasons of the Mars environment.

Successful development of processes established coaxial cable hardware fatigue limits, which were well beyond the expected in-flight exposures. In keeping with traditional qualification philosophy, this was accomplished by subjecting flight-representative coaxial cables to temperature cycling of the same depth as expected in-flight, but for three times the expected number of in-flight thermal cycles.

Insertion loss and return loss tests were performed on the coaxial cables during the thermal chamber breaks. A vector network analyzer was calibrated and operated over the operational frequency range 7.145 to 8.450 GHz. Even though some of the exposed cables function only at UHF frequencies (approximately 400 MHz), the testing was more sensitive, and extending the test range down to 400 MHz would have cost frequency resolution.

The Gore flexible coaxial cables, which were the subject of these tests, proved to be robust and displayed no sign of degradation due to the 3X exposure to the punishing Mars surface operations cycles.

This work was done by Rajeshuni Ramesham, Wayne L. Harvey, Sam Valas, and Michael C. Tsai of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47452

Using Spare Logic Resources To Create Dynamic Test Points

Goddard Space Flight Center, Greenbelt, Maryland

A technique has been devised to enable creation of a dynamic set of test points in an embedded digital electronic system. As a result, electronics contained in an application specific circuit [e.g., gate array, field programmable gate array (FPGA)] can be internally "probed," even when contained in a closed housing during all phases of test.

In the present technique, the test points are not fixed and limited to a small number; the number of test points can vastly exceed the number of buffers or pins, resulting in a compact footprint. Test points are selected by means of spare logic resources within the ASIC(s) and/or FPGA(s). A register is programmed with a command, which is used to select the signals that are sent off-chip and out of the housing for monitoring by test engineers and external test equipment.

The register can be commanded by any suitable means: for example, it could be commanded through a command port that would normally be used in the operation of the system. In the original application of the technique, commanding of the register is performed via a MIL-STD-1553B communication subsystem.

This work was done by Richard Katz and Igor Kleyner of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15490-1