February 1997

Vol. 21 No. 2

TECH BRIEFS

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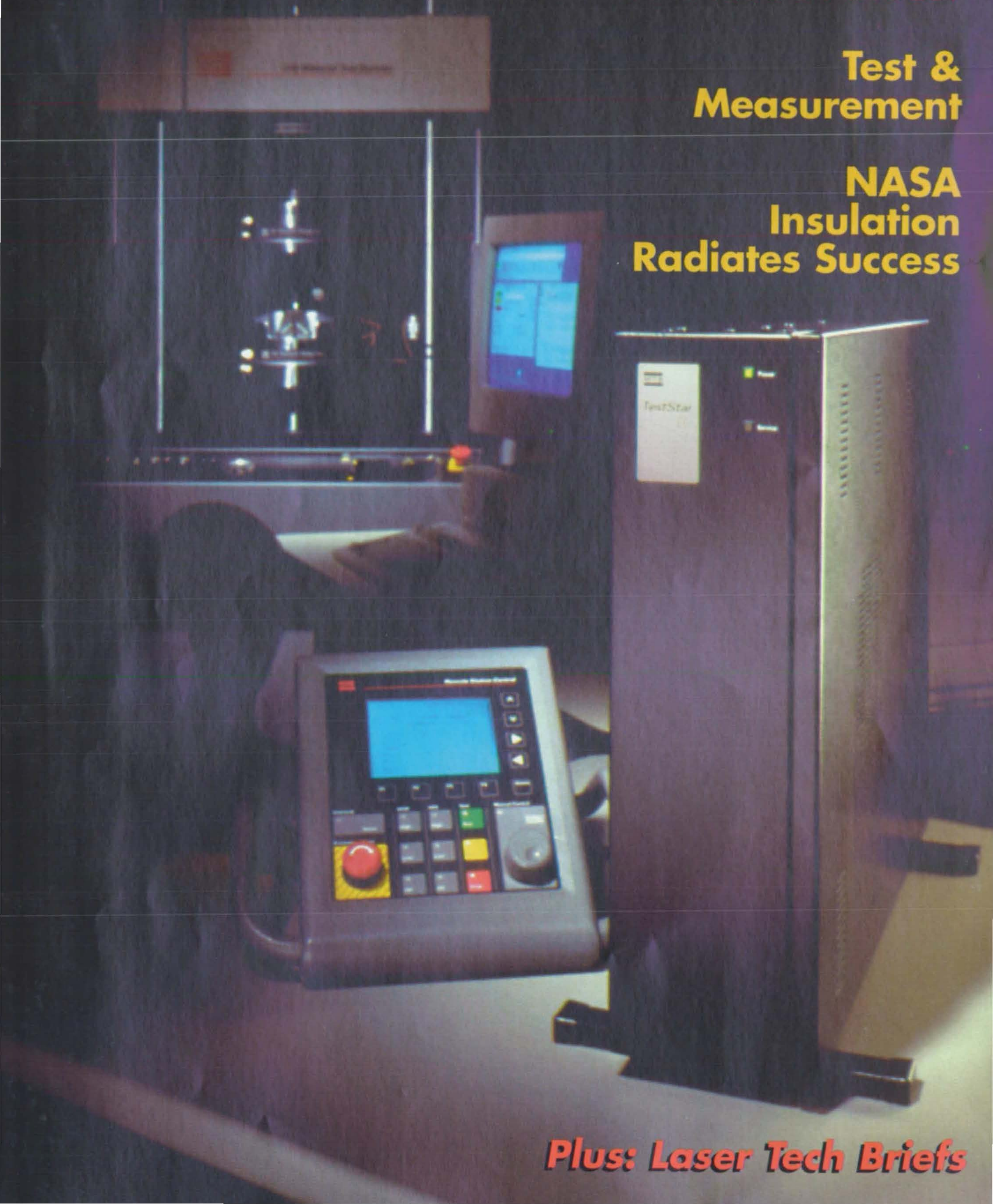

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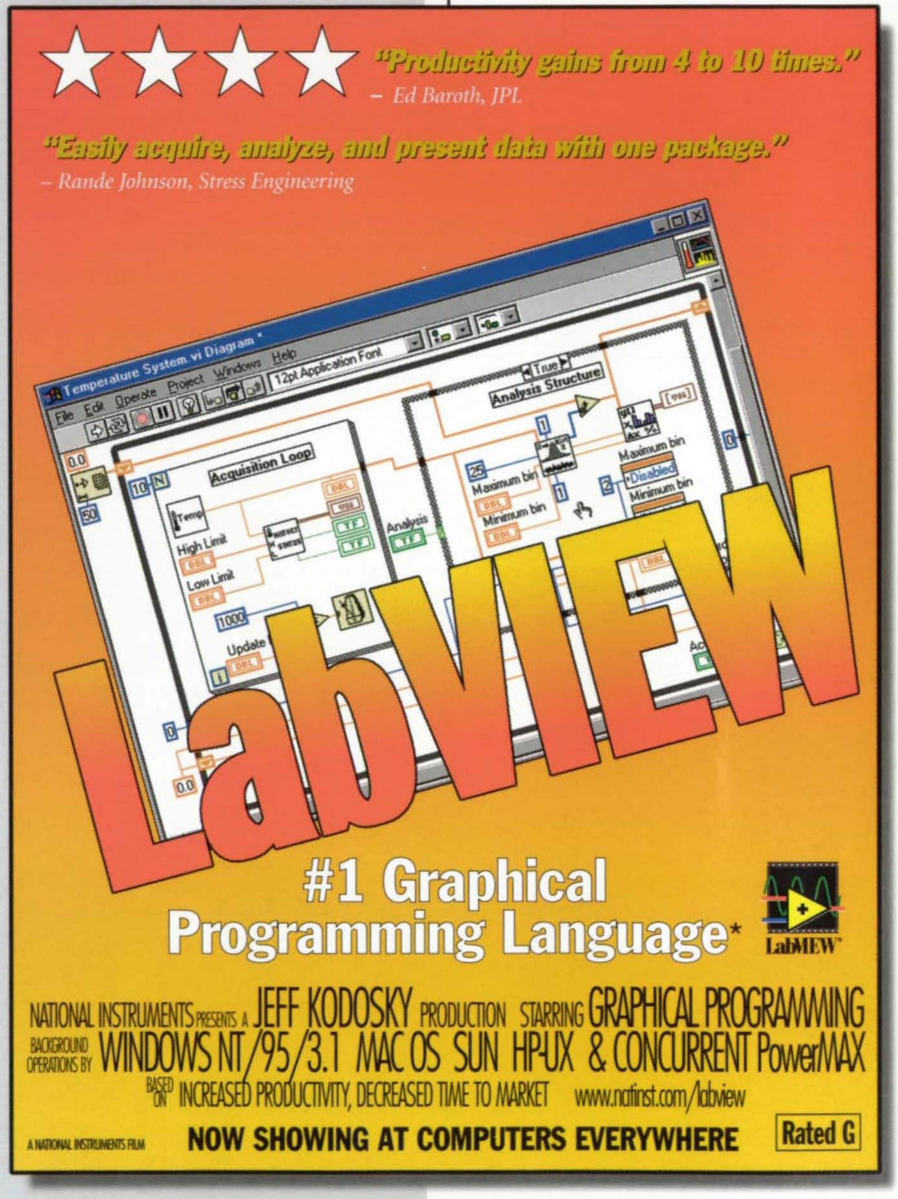

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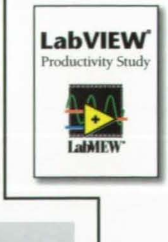

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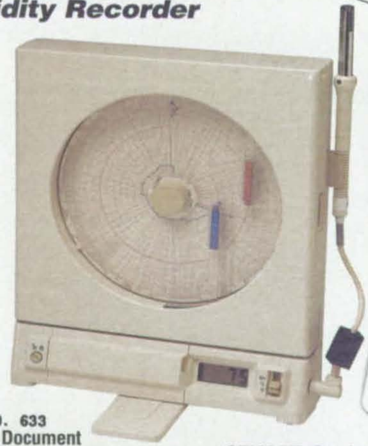

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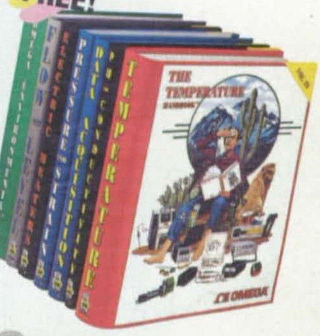

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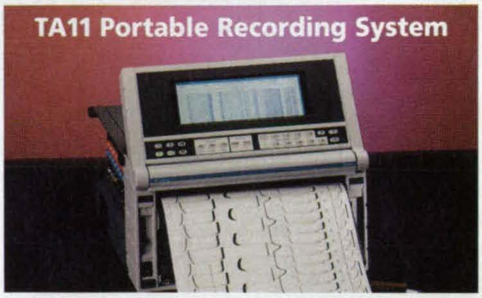

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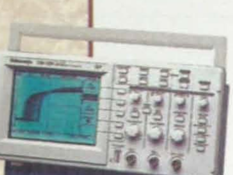

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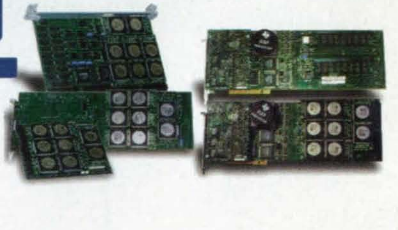

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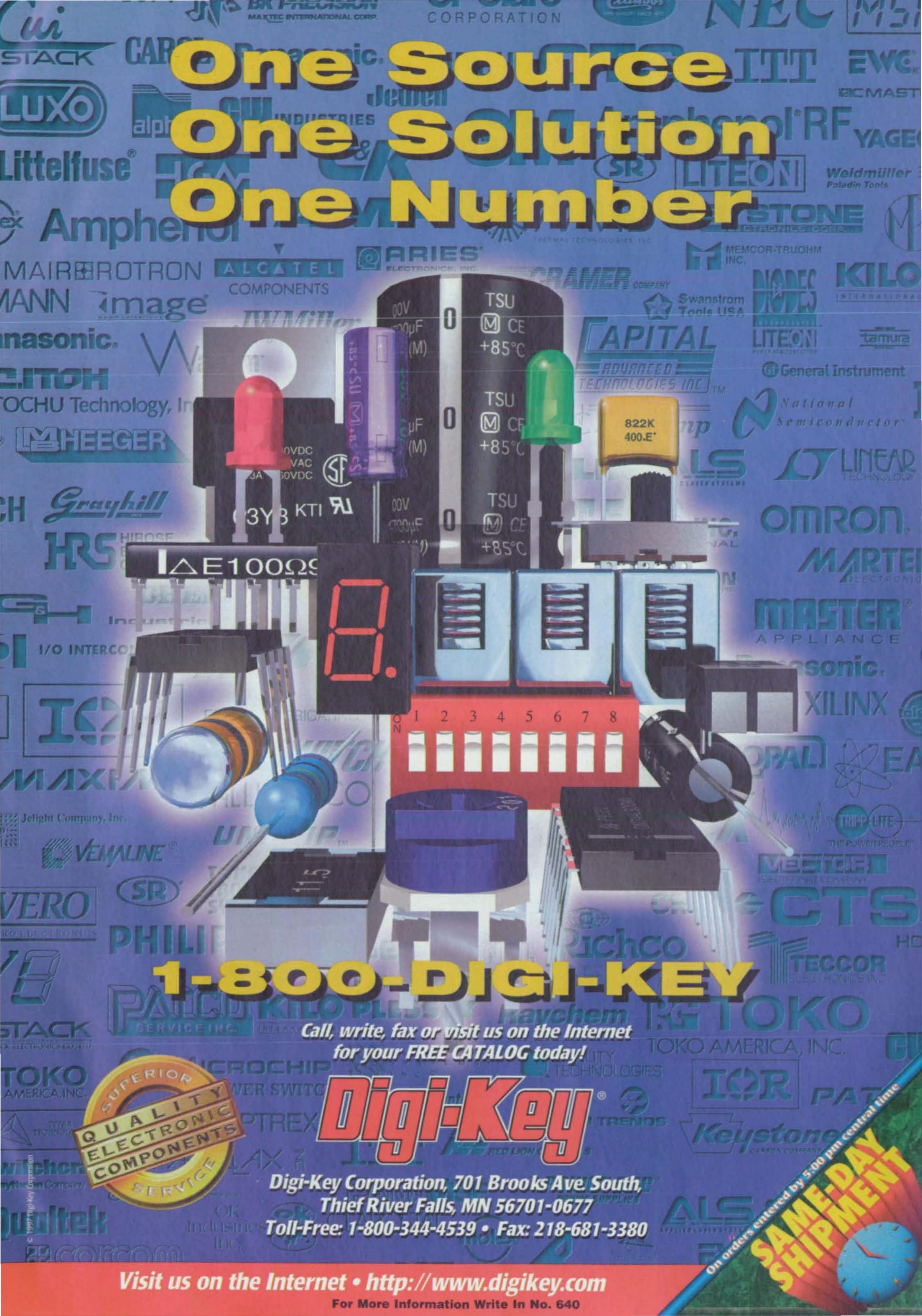

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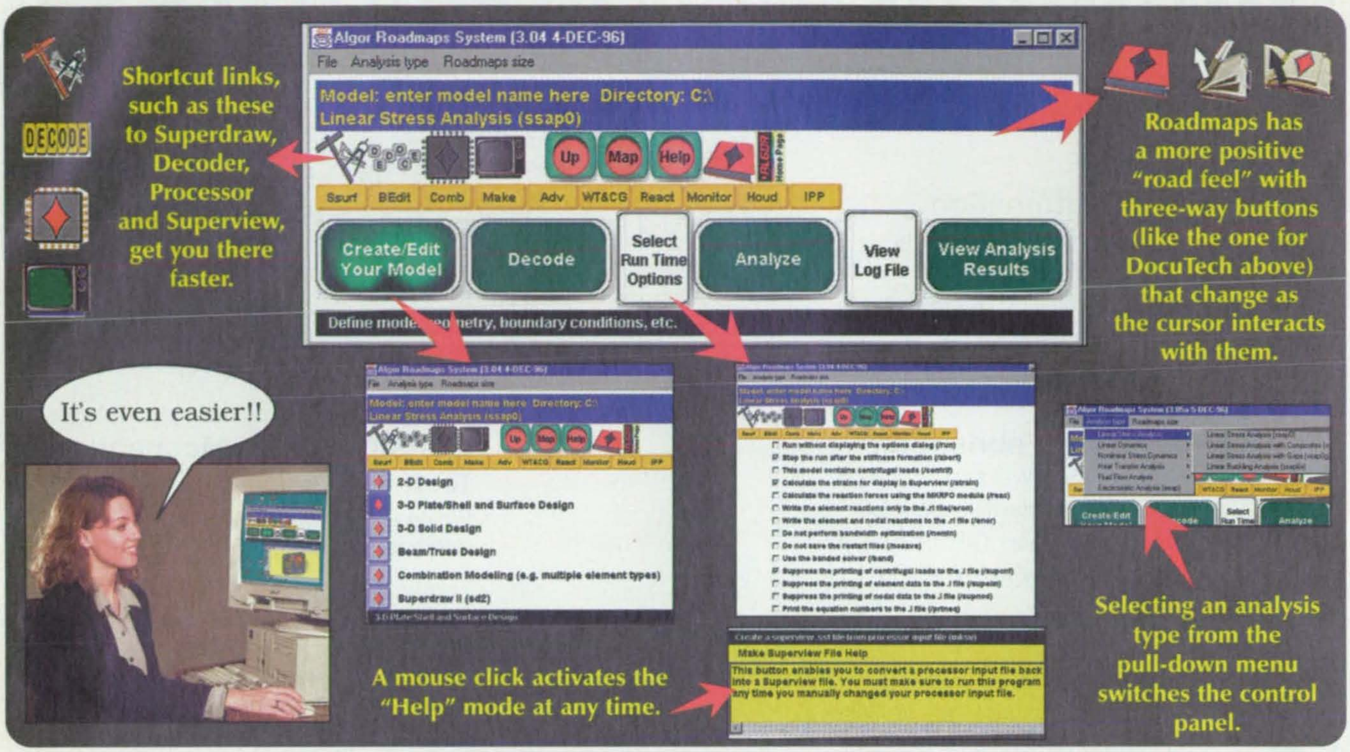
Energy Q radiant barrier from Tech 2000, Roswell, GA, was derived from materials developed by NASA and is finding applications in diverse industries, including building insulation. Pictured is Produce Exchange Warehouse in Nogales, AZ, a 55,000-square-foot facility lined with Energy Q. Inside, the temperature dropped 15° without increasing energy consumption. For more information, see Mission Accomplished on page 22.

Photo courtesy of Tech 2000

The Easiest Finite Element Analysis Just Got Easier!



☐ Run without displaying the options dialog (/run)
☑ Stop the run after the stiffness formation (/sbert)
☐ This model contains centrifugal loads (/centrif)
☑ Calculate the strains for display in Superview (/strain)
☐ Calculate the reaction forces using the MKRFO module (/reac)
☐ Write the element reactions only to the .rl file(/eron)
☐ Write the element and nodal reactions to the .rl file (/enor)
☐ Do not perform bandwidth optimization (/nomin)
☐ Do not save the restart files (/nosave)
☐ Use the banded solver (/band)
☑ Suppress the printing of centrifugal loads to the .l file (/supcnf)
☐ Suppress the printing of element data to the .l file (/supelm)
☐ Suppress the printing of nodal data to the .l file (/supnod)
☐ Print the equation numbers to the .l file (/prtneq)

This button enables you to convert a processor input file back into a Superview file. You must make sure to run this program any time you manually changed your processor input file.

Shortcut links, such as these to Superdraw, Decoder, Processor and Superview, get you there faster.

Roadmaps has a more positive "road feel" with three-way buttons (like the one for DocuTech above) that change as the cursor interacts with them.

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A mouse click activates the "Help" mode at any time.

Selecting an analysis type from the pull-down menu switches the control panel.

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- Advanced menu system has shortcut links for experienced power users.
- Pull-down menus activate the control panel for the type of analysis or simulation selected.
- Help screens appear as an extension to the bottom of the Roadmaps control panel.
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1a - 14a Laser Tech Briefs
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Follows page 64 in selected editions only.

On the cover:
This month's Special Focus on Test and Measurement, which begins on page 27, encompasses equipment ranging from position measurement systems and flow controllers, to scales and thermometers. The TestStar™ digital test control system from MTS Systems Corp., Eden Prairie, MN, tests materials and components in a myriad of industries.

Photo courtesy of MTS Systems Corp.

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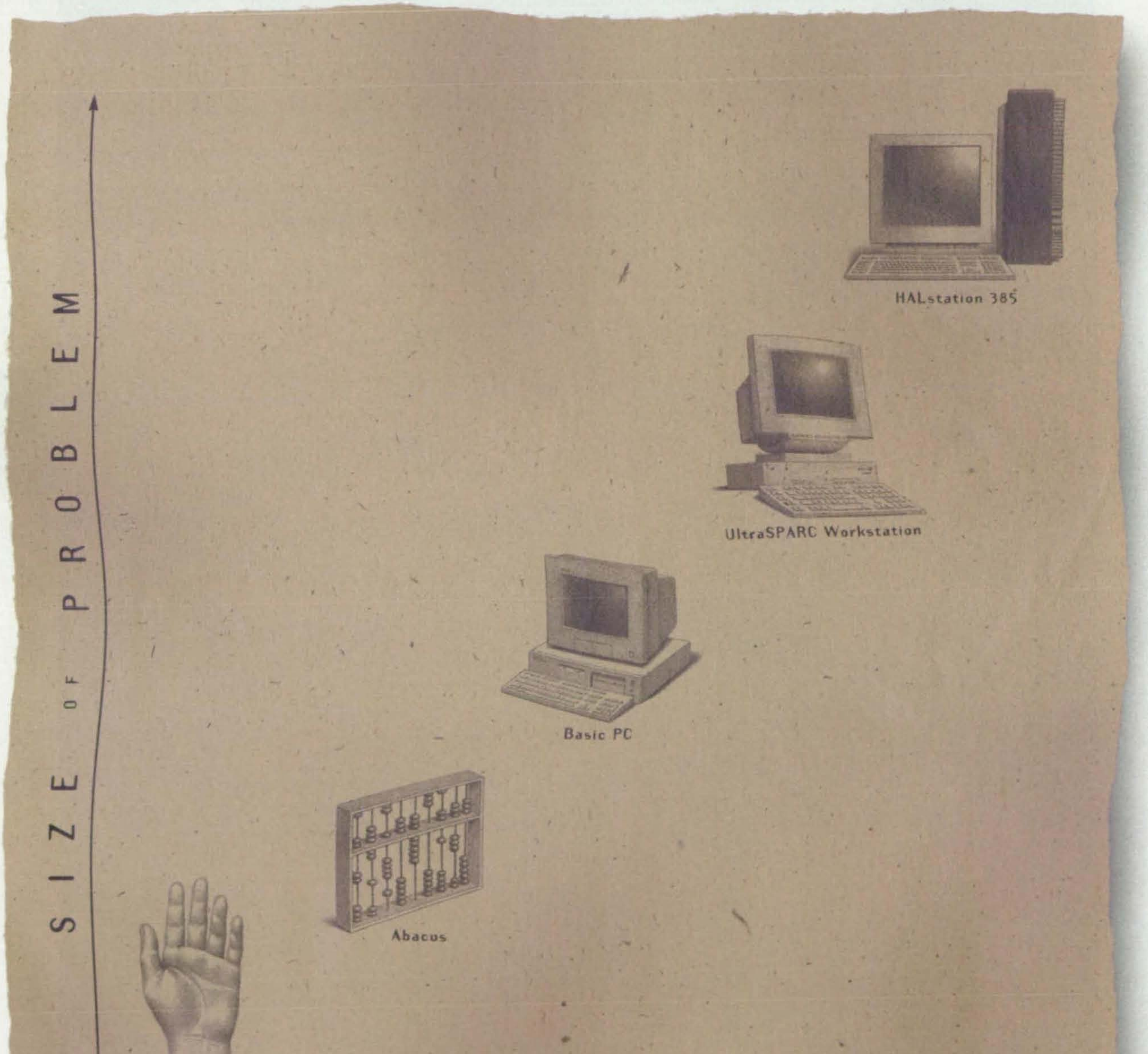

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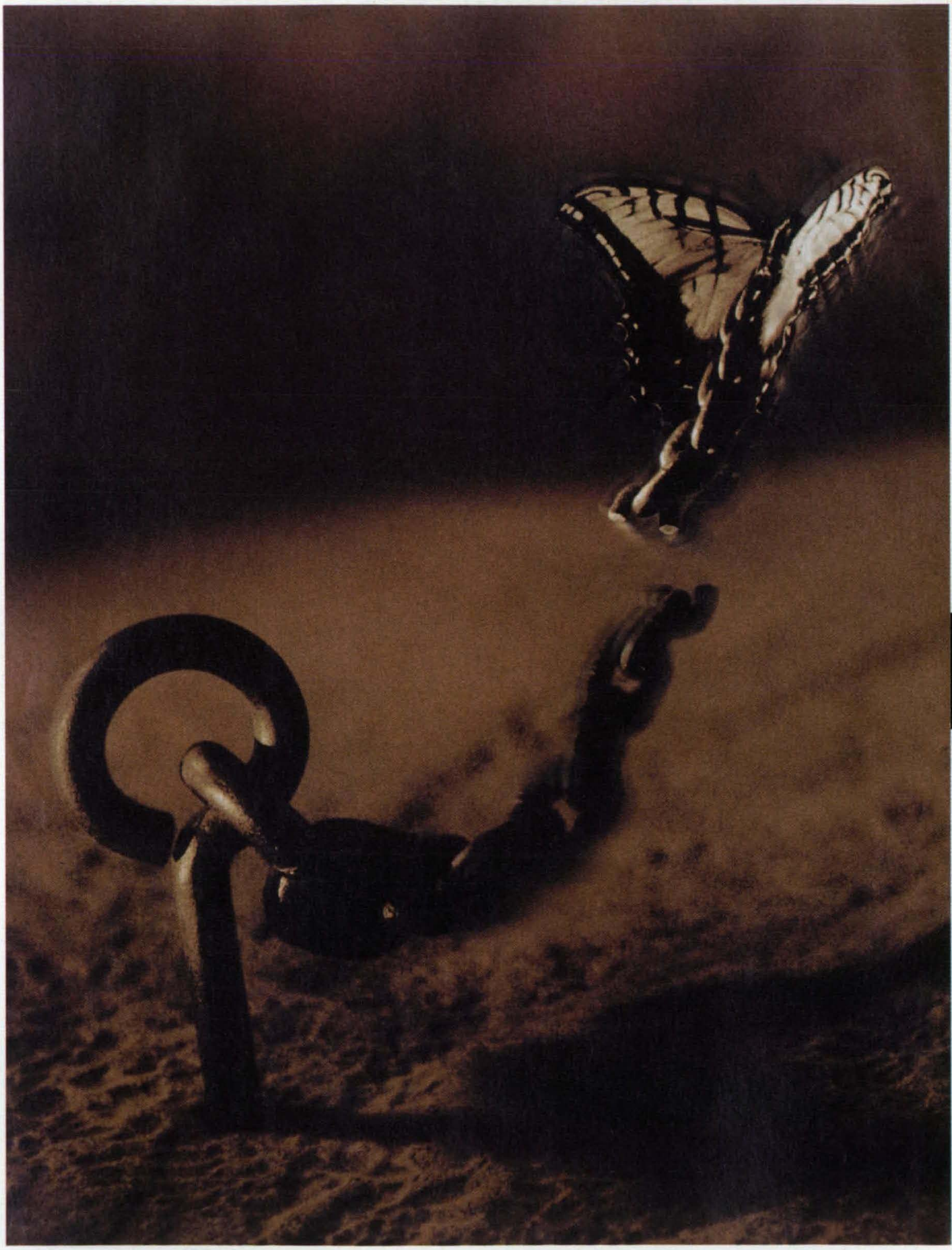

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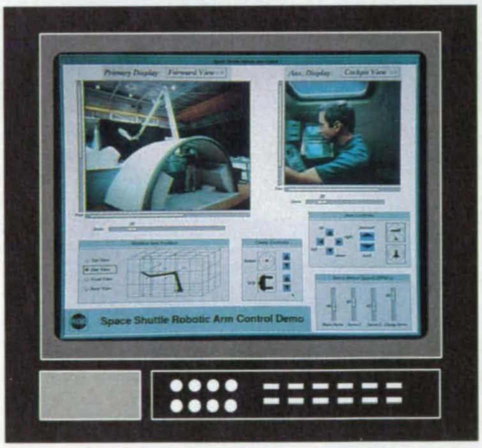

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S. Calif., AZ, NM, NV (For *NASA Tech Briefs*)	Blake Dahlgren at (310) 288-0391
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For More Information Write In No. 652

NASA Commercial Technology Team

NASA's R&D efforts produce a robust supply of promising technologies with applications in many industries. A key mechanism in identifying commercial applications for this technology is NASA's national network of commercial technology organizations. The network includes ten NASA field centers, six Regional Technology Transfer Centers (RTTCs), the National Technology Transfer Center (NTTC), business support organizations, and a full tie-in with the Federal Laboratory Consortium (FLC) for Technology Transfer. Call (360) 683-1005 for the FLC coordinator in your area.

NASA's Technology Sources

If you need further information about new technologies presented in *NASA Tech Briefs*, request the Technical Support Package (TSP) indicated at the end of the brief. If a TSP is not available, the Commercial Technology Office at the NASA field center that sponsored the research can provide you with additional information and, if applicable, refer you to the innovator(s). These centers are the source of all NASA-developed technology.

Ames Research Center
Selected technological strengths: Fluid Dynamics; Life Sciences; Earth and Atmospheric Sciences; Information, Communications, and Intelligent Systems; Human Factors.
Bruce Webbon
(415) 604-6646
bwebbon@mail.arc.nasa.gov

Dryden Flight Research Center
Selected technological strengths: Aerodynamics; Aeronautics Flight Testing; Aeropropulsion; Flight Systems; Thermal Testing; Integrated Systems Test and Validation.
Lee Duke
(805) 258-3802
duke@louie.dfrf.nasa.gov

Goddard Space Flight Center
Selected technological strengths: Earth and Planetary Science Missions; LIDAR; Cryogenic Systems; Tracking; Telemetry; Command.
George Alcorn
(301) 286-5810
galcorn@gsfc.nasa.gov

Jet Propulsion Laboratory
Selected technological strengths: Near/Deep-Space Mission Engineering; Microspacecraft; Space Communications; Information Systems; Remote Sensing; Robotics.
Merle McKenzie
(818) 354-2577
merle.mckenzie@ccmail.jpl.nasa.gov

Johnson Space Center
Selected technological strengths: Artificial Intelligence and Human Computer Interface; Life Sciences; Human Space Flight Operations; Avionics; Sensors; Communications.
Hank Davis
(713) 483-0474
hdavis@gp101.jsc.nasa.gov

Kennedy Space Center
Selected technological strengths: Environmental Monitoring; Sensors; Corrosion Protection; Bio-Sciences; Process Modeling; Work Planning/Control; Meteorology.
Bill Sheehan
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Langley Research Center
Selected technological strengths: Aerodynamics; Flight Systems; Materials; Structures; Sensors; Measurements; Information Sciences.
Dr. Joseph S. Heyman
(804) 864-6006
j.s.heyman@larc.nasa.gov

Lewis Research Center
Selected technological strengths: Aeropropulsion; Communications; Energy Technology; High Temperature Materials Research.
Ann Heyward
(216) 433-3484
ann.o.heyward@lerc.nasa.gov

Marshall Space Flight Center
Selected technological strengths: Materials; Manufacturing; Nondestructive Evaluation; Biotechnology; Space Propulsion; Controls and Dynamics; Structures; Microgravity Processing.
Harry Craft
(205) 544-5419
harry.craft@msfc.nasa.gov

Stennis Space Center
Selected technological strengths: Propulsion Systems; Test/Monitoring; Remote Sensing; Nonintrusive Instrumentation.
Kirk Sharp
(601) 688-1929
ksharp@ssc.nasa.gov

NASA-Sponsored Commercial Technology Organizations

These organizations were established to provide rapid access to NASA and other federal R&D and foster collaboration between public and private sector organizations. They also can direct you to the appropriate point of contact within the Federal Laboratory Consortium. To reach the Regional Technology Transfer Center nearest you, call (800) 472-6785.

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Far-West Technology Transfer Center
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Dr. William Gasko
Center for Technology Commercialization
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J. Ronald Thornton
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Lani S. Hummel
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Chris Coburn
Great Lakes Industrial Technology Transfer Center
Battelle Memorial Institute
(216) 734-0094

NASA ON-LINE: Go to NASA's Commercial Technology Network (CTN) on the World Wide Web at **http://nctn.hq.nasa.gov** to search NASA technology resources, find commercialization opportunities, and learn about NASA's national network of programs, organizations, and services dedicated to technology transfer and commercialization.

NASA Program Offices

At NASA Headquarters there are seven major program offices that develop and oversee technology projects of potential interest to industry. The street address for these strategic business units is: NASA Headquarters, 300 E St. SW, Washington, DC 20546.

Gene Pawlik
Small Business Innovation Research Program (SBIR)
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gpawlik@oact.hq.nasa.gov

Robert Norwood
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rnorwood@oact.hq.nasa.gov

Philip Hodge
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Gerald Johnson
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Bill Smith
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Bert Hansen
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Granville Paules
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gpaules@mtpe.hq.nasa.gov

NASA's Business Facilitators

NASA has established several organizations whose objectives are to establish joint sponsored research agreements and incubate small start-up companies with significant business promise.

Karen Robbins
American Technology Initiative
Menlo Park, CA
(415) 325-5353

Dr. Jill Fabricant
Johnson Technology Commercialization Center
Houston, TX
(713) 335-1250

John Gee
Ames Technology Commercialization Center
Sunnyvale, CA
(408) 734-4700

Dan Morrison
Mississippi Enterprise for Technology
Stennis Space Center, MS
(800) 746-4699

If you are interested in information, applications, and services relating to satellite and aerial data for Earth resources, contact: Dr. Stan Morain, **Earth Analysis Center,** (505) 277-3622. For software developed with NASA funding, contact **NASA's Computer Software Management and Information Center (COSMIC)** at phone: (706) 542-3265; Fax: (706) 542-4807; E-mail: http://www.cosmic.uga.edu or service@cosmic.uga.edu.

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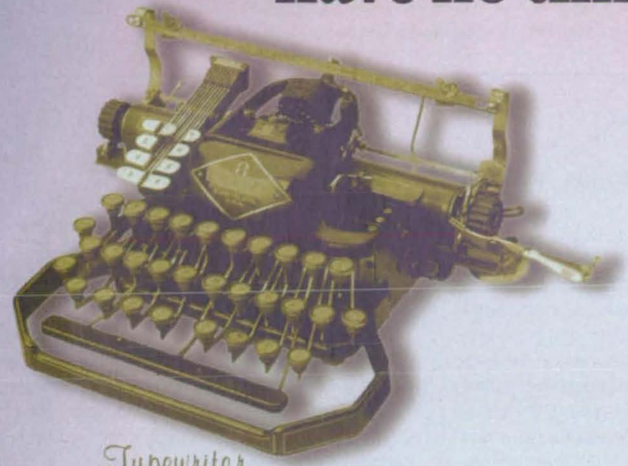
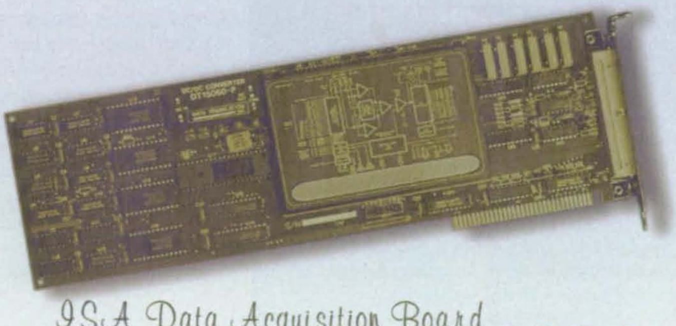


Typewriter c. 1922

Adding Machine c. 1941

Rotary Telephone c. 1953



ISA Data Acquisition Board c. 1984

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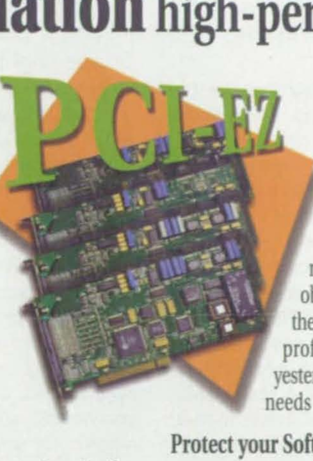

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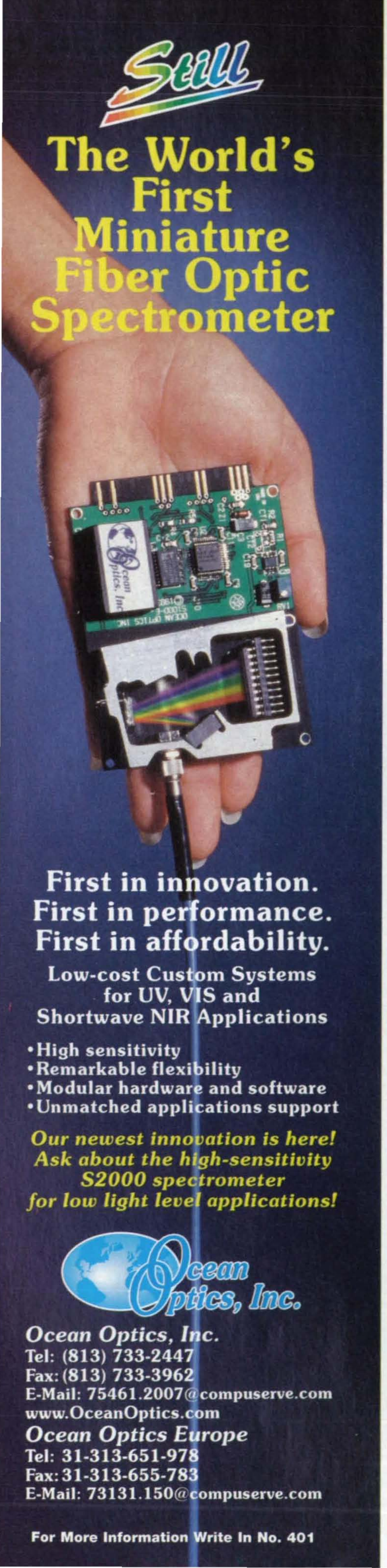

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NASA PATENTS

Over the past three decades, NASA has granted more than 1000 patent licenses in virtually every area of technology. The agency has a portfolio of 3000 patents and pending applications available now for license by businesses and individuals, including these recently patented inventions:

Push Type Fastener

(U.S. Patent No. 5,562,375)

Inventor: Steven A. Jackson, Marshall Space Flight Center

Conventional "push-to-latch pull-to unlatch" fasteners for securing a fixed to a removable part have advantages of small size and weight. But, while suitable for instances in which access is available from one side only, they are sometimes impractical when the head size is too small to be grasped for pulling because the user has bulky gloves or limited dexterity. Where access is available from both sides, and small size and weight remain crucial, the present invention substitutes a "push-push" approach. The latch consists of a plunger having a rounded end and a threaded end, an expandable grommet, and a rounded head to be secured to the threaded end. The plunger passes through a hole in the removable part, the head is put on it, and it is passed through a similar hole in the fixed part. When a large annular radial flange on the grommet abuts the removable part, further pushing engages an external camming surface on the plunger with internal surfaces of the grommet, resulting in its expansion and the latching effect. Decoupling requires only pushing the attachable head.

For More Information Write In No. 771

Compact Solar Simulator with a Small Subtense Angle and Controlled Magnification Optics

(U.S. Patent No. 5,568,366)

Inventor: Kent S. Jefferies, Lewis Research Center

This solar simulator is the first that will be used for vacuum-tank testing of a solar dynamic power system. Major disadvantages of prior-art simulators are their large size and high cost, and the large angular size of the light source or pseudosun, which in most simulators has a diameter that subtends 4 degrees or more. But test requirements call for an angular size of one degree, translating to 1600 W/sq. m of radiant energy. The invention meets the requirement at reduced cost and volume. It uses a newly designed lamp module to create uniformity directly on a test plane, and a segmented turning mirror rather than a less efficient optical mixer. Cost and size are cut by reducing the number of lamp modules and by eliminating the prior art's collimating mirror. Efficiency is increased by controlled magnification optics that vary tangential magnification so that the product of tangential and sagittal magnification, and thus the intensity that reaches the test plane, is constant.

For More Information Write In No. 775

Process for Non-Contact Removal of Organic Coatings from the Surface of Paintings

(U.S. Patent No. 5,560,781)

Inventors: Bruce A. Banks and Sharon K. Rutledge, Lewis Research Center

To remove degraded organic protective coatings from paintings, previous methods typically called for immersing the painting in organic solvents or rolling a swab containing the solvent over the surface, both of which alter the pigment surface. In the new method, degraded organic coatings such as lacquers, acrylics, natural resins, and polyurethane are safely removed without contact with the surface. The painting is placed inside a vacuum chamber and exposed to an atomic oxygen directed beam generated by an electron cyclotron resonance plasma or other atomic oxygen source. The reaction of beam and coating produces a gaseous byproduct that is pumped out through the vacuum system. The atomic oxygen penetrates the organic coating, but does not react with the inorganic pigment particles. Low and high spots on the painting surface can both be cleaned without damage to the underlying pigment.

For More Information Write In No. 772

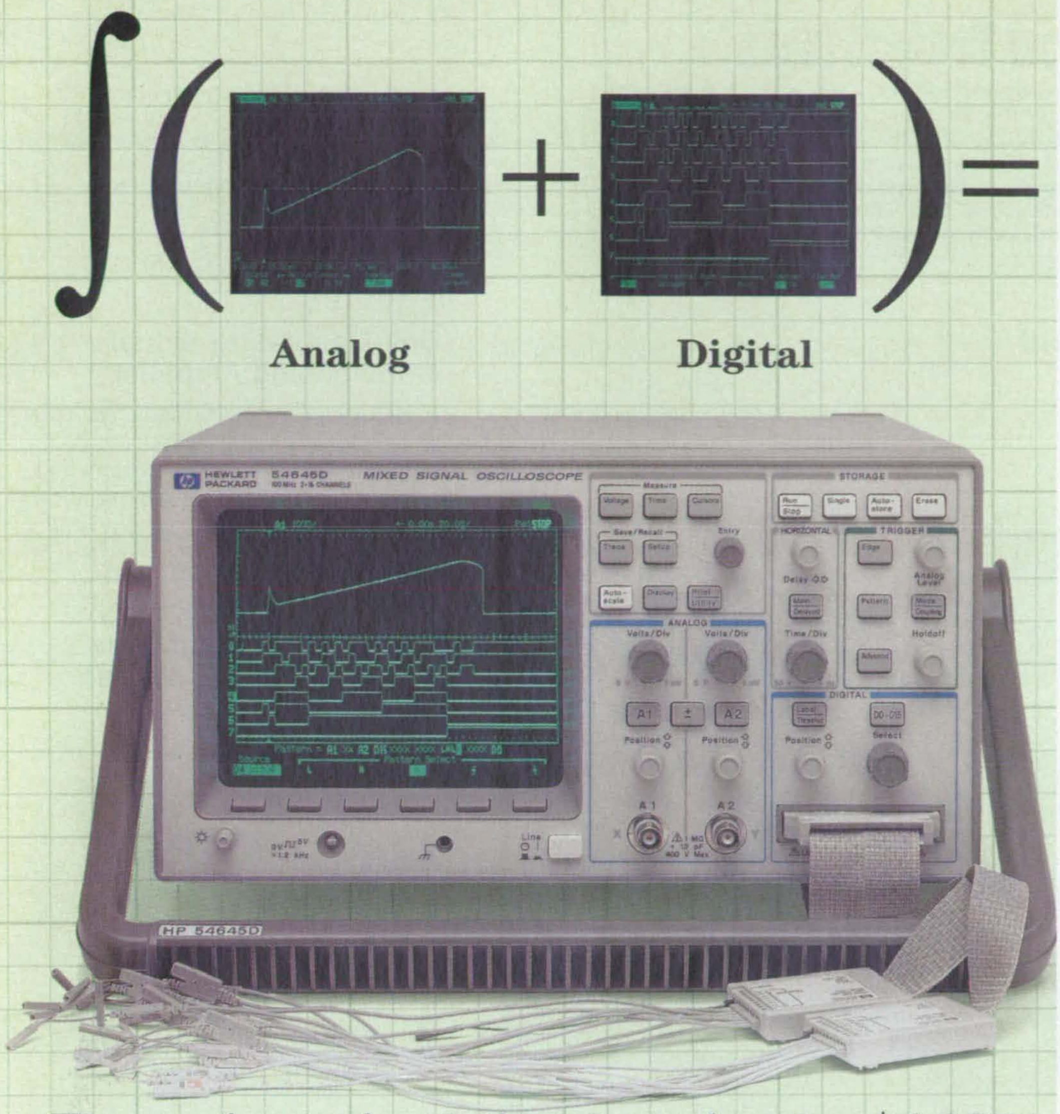
Absorbent Pads for Containment, Neutralization, and Clean-Up of Environmental Spills Containing Chemically Reactive Agents

(U.S. Patent No. 5,562,963)

Inventor: Dennis D. Davis, Marshall Space Flight Center

The development is a pad that absorbs a liquid spill and also neutralizes reactive agents within it. The pad's porous surface carries an inert absorbent interior component which in turn surrounds another absorbent core bearing a chemical reagent capable of reacting with a toxic, dangerous, or just unwanted component of the spill. The absorbing component draws the liquid chemical spill through the porous surface to the core so that it is neutralized while being cleaned from the substrate. The core of the pad may be an acid for the neutralization of caustic spills, a base reagent for the neutralization of acid spills, a chelating or precipitating reagent for spills containing metallic salts in solution, or an oxidizing agent for reaction with spills containing organic materials such as the rocket fuel hydrazine. The flexible invention can be used for cleaning a whole host of noxious chemicals, and the pads containing the now harmless spill components are easily scooped up for safe disposal.

For More Information Write In No. 776



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New Product Ideas

New Product Ideas are just a few of the many innovations described in this issue of *NASA Tech Briefs* and having promising commercial applications. Each is discussed further on the referenced page in the appropriate section in this issue. If you are interested in developing a product from these or other NASA innovations, you can receive further technical information by requesting the TSP referenced at the end of the full-length article or by writing the Commercial Technology Office of the sponsoring NASA center (see page 14).

Two-Way, Noncoherent Precise Doppler Measurement System

This Doppler transceiver needs only one fixed-frequency oscillator to generate all transmitter and receiver frequencies. The result is that complexity, input power, size, and cost are reduced.
(See page 46.)

Self-Calibrating Signal-Conditioning Amplifier

An analog signal-conditioning amplifier for use with a transducer repeatedly calibrates itself using stable, accurate internal voltages. The accuracy is maintained during warmup, variations in temperature and humidity, and aging of components.
(See page 48.)

Measuring Photoinduced Surface Acoustic Waves by AFM

A photo-surface-acoustic-wave/atomic-force microscopy is an experimental technique that may prove useful in obtaining high-resolution data on spatial variations in the chemical compositions of surface layers on solid objects.This technique could provide analytical chemistry data at high spatial resolution.
(See page 52.)

Variable-Compliance Wrist for Robotic Manipulator

This robot wrist can be rigid or compliant within a limited range of motion. The manipulator can thus be adapted to a variety of tasks; for example, insertion of an object into a cavity with a precise fit.
(See page 65.)

Portable Drilling Apparatus for Subsurface Sampling

This apparatus can acquire samples of subsurface material at depths of as much as 1 m. The apparatus could likely be designed for remote-controlled sampling of snow, ice, sand, soil, and soft rock in hazardous or otherwise inaccessible locations.
(See page 66.)

Growing Three-Dimensional Corneal Tissue in a Bioreactor

This method can be used to prepare corneal tissues either from *in vitro* cultures of a patient's own cells or from a well-defined culture from a human donor. The method could overcome the shortage of donated corneal tissue.
(See page 74.)

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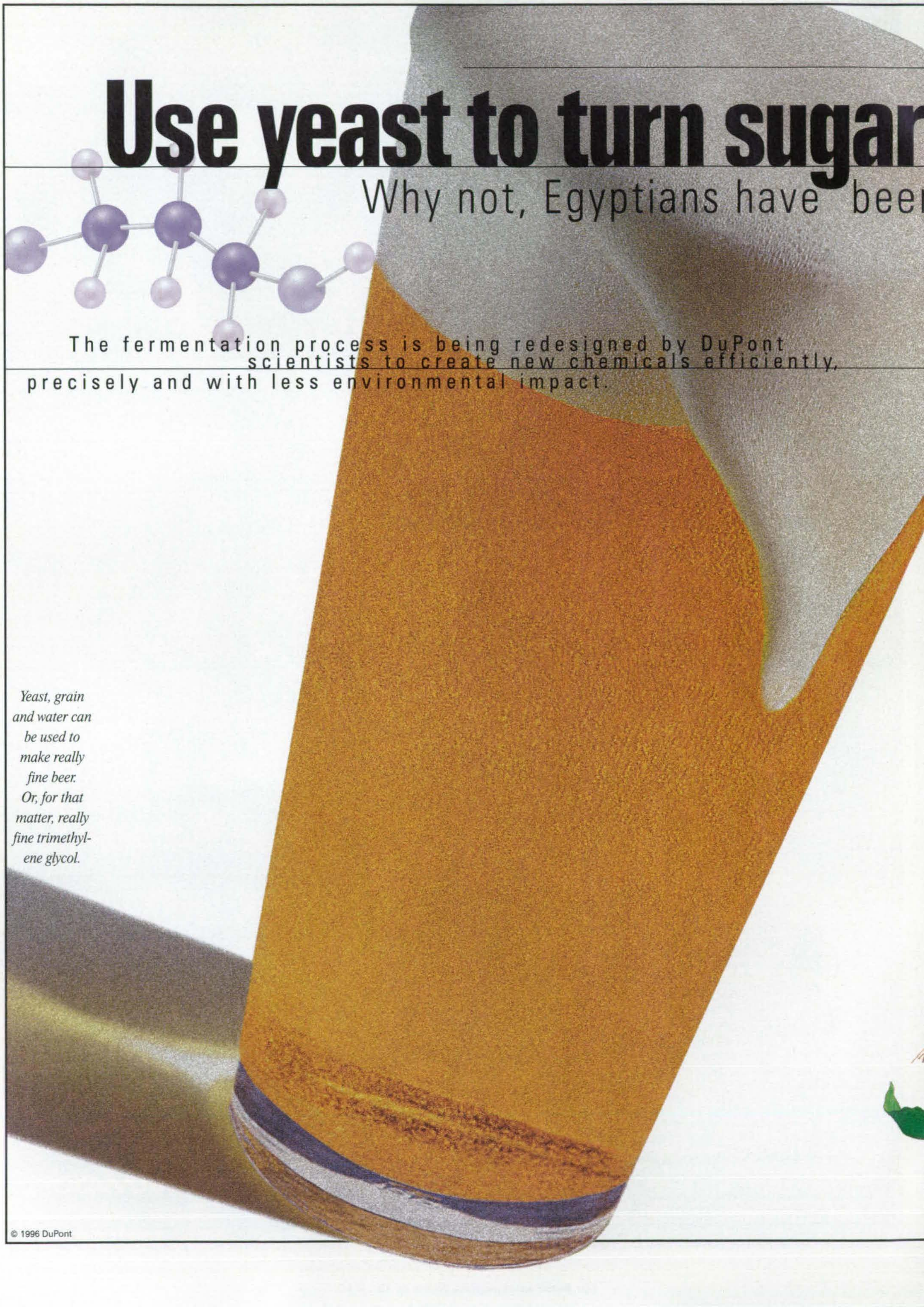


Use yeast to turn sugar

Why not, Egyptians have bee

The fermentation process is being redesigned by DuPont scientists to create new chemicals efficiently, precisely and with less environmental impact.

Yeast, grain and water can be used to make really fine beer. Or, for that matter, really fine trimethylene glycol.

© 1996 DuPont

into other molecules?

doing it for 4,000 years.

The transformation of sugars into alcohol by microscopic organisms has been known for a very long time. But only since the advent of genetic engineering is it feasible to think about harnessing the sophistication of biological systems to create molecules that are difficult to synthesize by traditional chemical methods.

For example, the polymer polytrimethylene terephthalate (3GT) has enhanced properties as compared to traditional polyester (2GT). Yet commercialization has been slow to come because of the high cost of making trimethylene glycol (3G), one of 3GT's monomers.

Comfortable, easy-care apparel may soon be made with fibers spun from chemicals that have been fermented from sugar.

Working the bugs in

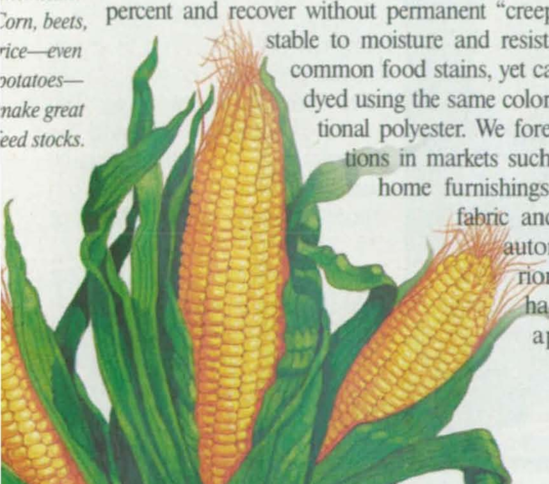
The secret to producing 3G can be found in the cellular machinery of certain unrelated microorganisms. Some naturally occurring yeasts convert sugar to glycerol, while a few bacteria can change glycerol to 3G. The rub is that no single natural organism has been able to do both.

Through recombinant DNA technology, an alliance of scientists from DuPont and Genencor International has created a single microorganism with all of the enzymes required to turn sugar into 3G. This breakthrough is opening the door to low-cost, environmentally sound, large-scale production of 3G. The eventual cost of 3G by this process is expected to approach that of ethylene glycol (2G).

is no longer necessary o start with a barrel of l to produce chemicals. Corn, beets, rice—even potatoes— make great eed stocks.

A polymer for your thoughts

The 3GT polymer produced using our biosynthesized monomer has properties that exceed those of normal polyester. It is resilient and can be molded or extruded into fibers. The fibers are heat-settable and can be stretched at least 15 percent and recover without permanent "creep." They are stable to moisture and resistant to most common food stains, yet can be readily dyed using the same colors as conventional polyester. We foresee applications in markets such as apparel, home furnishings, upholstery fabric and carpet for automobile interiors. Even 3G has numerous applications. By combining it with various organic acids, polyols can be made as precursors to polyurethane elastomers and synthetic leathers.



A break for the environment

The 3G fermentation process requires no heavy metals, petroleum or toxic chemicals. In fact, the primary material comes from agriculture—glucose from cornstarch. Rather than releasing carbon dioxide to the atmosphere, the process actually captures it because corn absorbs CO_2 as it grows. All liquid effluent is easily and harmlessly biodegradable. What's more, 3GT can readily undergo methanolysis, a process that reduces polyesters to their original monomers. Post-consumer polyesters can thus be repolymerized and recycled indefinitely.

Can you play a role?

Throughout DuPont's history, many of our biggest contributions have come to market through collaboration with other companies. Development of 3GT could involve partnering with companies active in traditional polymer processing, separations technologies, recombinant DNA techniques, corn wet-milling and fermentation. If you possess these skills, or have ideas for end-use applications, we'd like to hear from you. Fax us on company letterhead with an indication of your interests to: DuPont, Dept. NT, 302-695-7615. Please limit your correspondence to nonproprietary, public-domain information only.

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Mission Accomplished

In the mid-1950s, when Clark E. Beck, PE, of Wright-Patterson Air Force Base discovered and pioneered the development of radiant barrier technology for NASA and the space program, he couldn't have envisioned the variety of applications for which the insulation material would someday be used. But today, thanks to Preston E. Smith and his company, Tech 2000 of Roswell, GA, radiant barrier technology has been spun-off into products as diverse as energy-saving home insulation, candy wrappings, footwear inserts, and protective clothing.

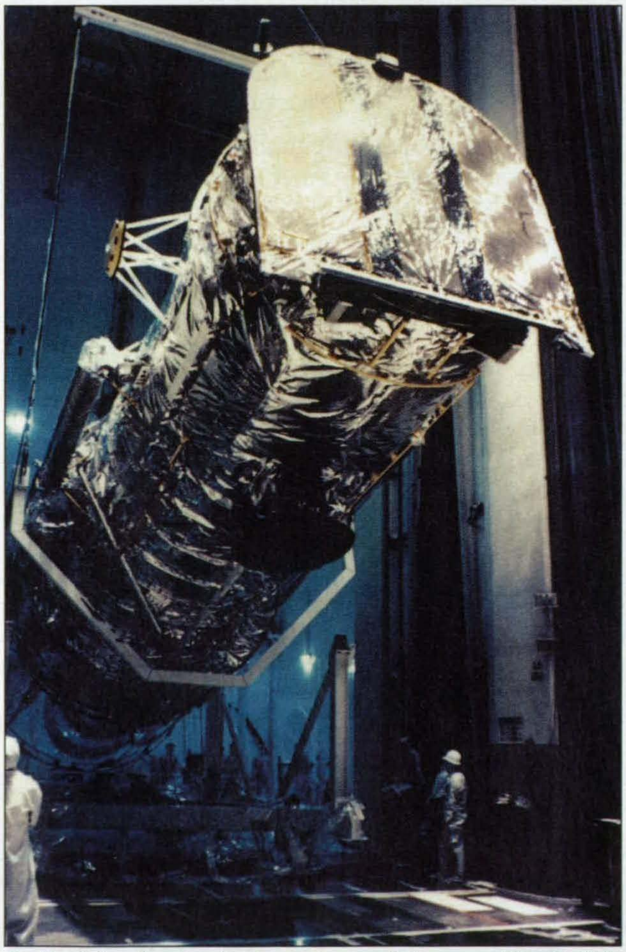
The radiation barrier has been in use by NASA since the Gemini and Apollo missions. The insulation was the prime element of the environmental control system that allowed Apollo astronauts to work inside the Command Module in shirt-sleeves, rather than in bulky space suits. The material maintained constant, comfortable temperatures inside the spacecraft, while temperatures outside fluctuated from -273°C to +238°C. Made of aluminized polymer film, the material provided a reflective surface that kept more than 95 percent of the radiated energy from reaching the interior of the spacecraft.

In addition, the radiant barrier was used to reduce the required thickness of the astronauts' space suits. Says Smith, "If it hadn't been for this technology, the U.S. space suit would have been seven feet thick." Since the Gemini and Apollo missions, the radiant barrier has been used on virtually all spacecraft, including unmanned missions where instruments require thermal protection. It is used in the current fleet of space shuttles to protect the on-board computers.

The material, called Energy Q, is made of 99 percent pure aluminum with a fire-resistant polypropylene insert. Small holes allow moisture to escape, while keeping longer heat waves from getting through. Weighing only slightly more than 17 pounds per thousand square feet, the material reflects 97 percent of the heat that strikes it.

All objects radiate heat – from wood to glass, and even ice. Energy Q works by reflecting 95 percent of radiant energy, which is the flow of invisible infrared rays from an object's surface. When installed in an attic, for example, it helps keep a building warmer in the winter and cooler in the summer, and is more environmentally friendly than traditional insulation such as fiberglass.

In new construction, the radiant barrier is placed between the wall studs and the exterior facing prior to the addition of aluminum, vinyl, or wood siding. In new roof installation, it is placed between the roof supports and the roof sheathing. When remodeling, the radiant barrier is placed on top of insulation blankets on the attic floor to reflect energy. In California, new homeowners using Energy Q insulation in their attics are given energy credits.



Radiant barrier insulation was used to wrap the Hubble Space Telescope, protecting it from extreme temperatures. Heat was reflected away from the telescope, while the heat from the instruments inside was maintained to provide them with a suitable working environment.

Terrestrial Uses for Space Technology

Inside a structure, the material can be used to wrap hot water pipes or tanks; insulate and provide a vapor barrier for steam baths or saunas; insulate steam pipes, refrigerant lines, heating, ventilating, or air conditioning ducts; line refrigerated holds on fishing vessels or in food-transport trailers; and insulate boats and aircraft.

On farms, the material protects livestock in stalls and stables, and insulates poultry and rabbit facilities. It also may have application as liners beneath the pavement on bridges in areas where cold weather causes them to freeze over, and beneath golf courses and parks to wrap sprinkler pipes.

Energy Q was used to cover a commercial gas-fired boiler room in a school, reducing the room temperature by 15°. As a result, the room above the boiler room was able to be used as a classroom. The material also increased the performance of a shrink-wrap oven used to shrink plastic protective coverings over auto seats before shipping. The barrier successfully reflected the energy inward. Smith estimates that in these applications, the suppliers realized a payback of 30 days of energy savings.

Tech 2000 has found uses for Energy Q as insulation in automobiles and trucks to protect passengers from engine, solar, and exhaust heat. NASCAR drivers use it to help protect them from the extremely high temperatures encountered in the vehicles' cockpits. (See Mission Accomplished, *NASA Tech Briefs*, August 1996, page 20.)

(continued on page 24)

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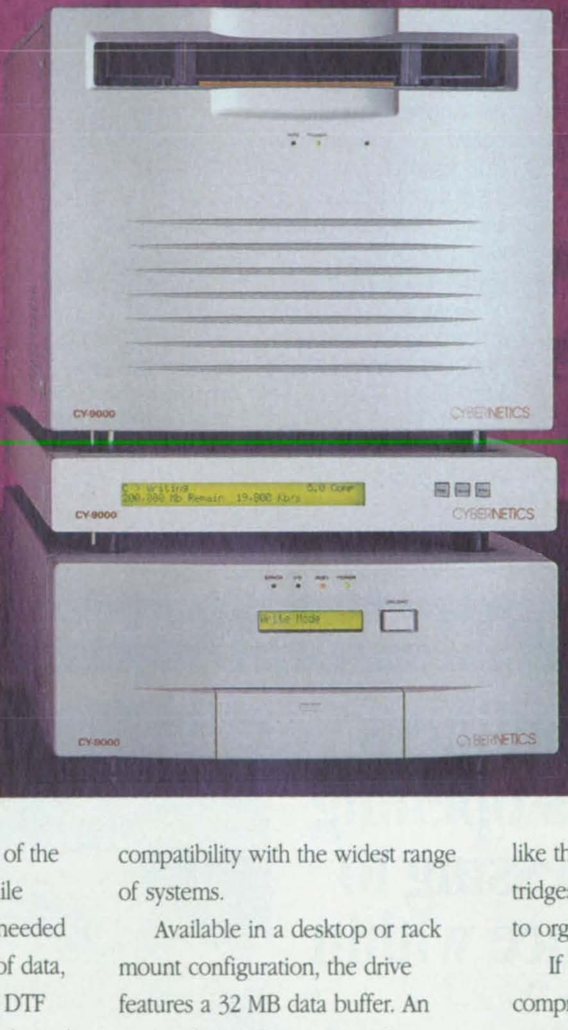

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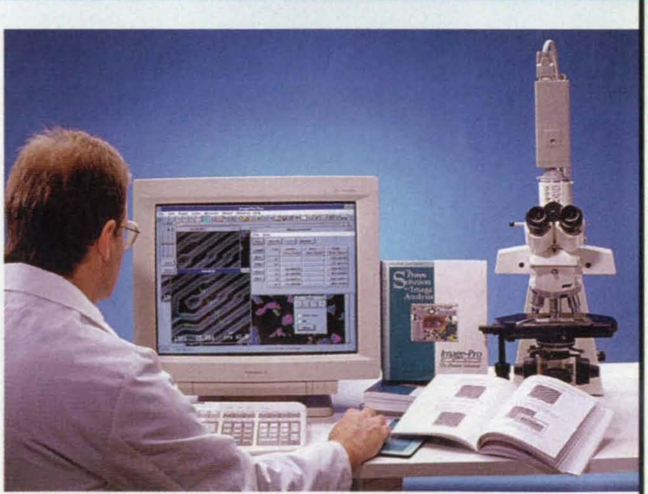
The potential applications of this material are just beginning to be realized. Clothing can be made with the material as an insulator; fire fighters' protective suits incorporate Energy Q, as do subzero liners for sleeping bags and emergency care thermal blankets. In the food transportation and storage field, Energy Q is used in refrigerated vans, railroad cars, picnic coolers, and pizza delivery bags. Seafood companies are using it to insulate bags and to line bulk containers.

In recognition of the commercial value of the Tech 2000-patented radiant barrier material, Smith was inducted last year into the U.S. Space Foundation's Space Technology Hall of Fame in Colorado Springs, CO. The Energy Q products also are featured as part of a 32-city tour conducted by NASA that began last summer and runs through this year.

Smith's company includes seven new product divisions and is exploring joint ventures worldwide to manufacture its products. Said Smith, "For years people laughed at me. They called me the tin man. But you tell me where there's not hot or cold, and I'll tell you where it won't work."

For more information on Energy Q products, contact Tech 2000 at 770 Old Roswell Place, Ste. J200, Roswell, GA 30076; Tel: 770-642-6316 or 800-390-4734; Fax: 770-642-7516.

The EZ Steamer restaurant and food service steam oven incorporates Energy Q insulation in the cooking compartment, maximizing heating efficiency.



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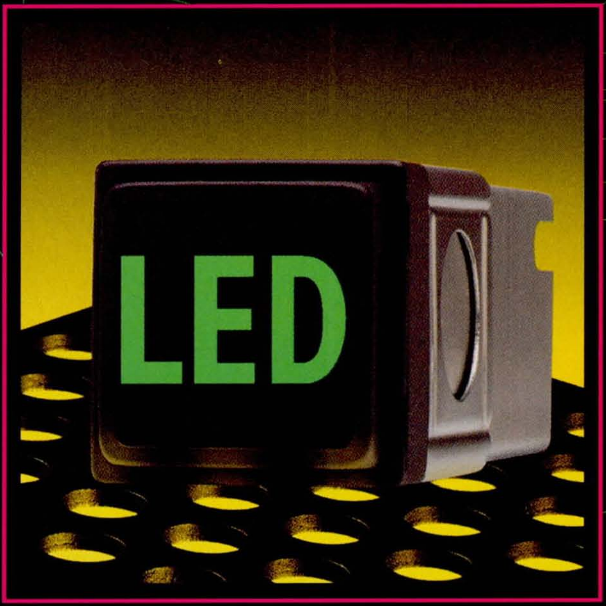

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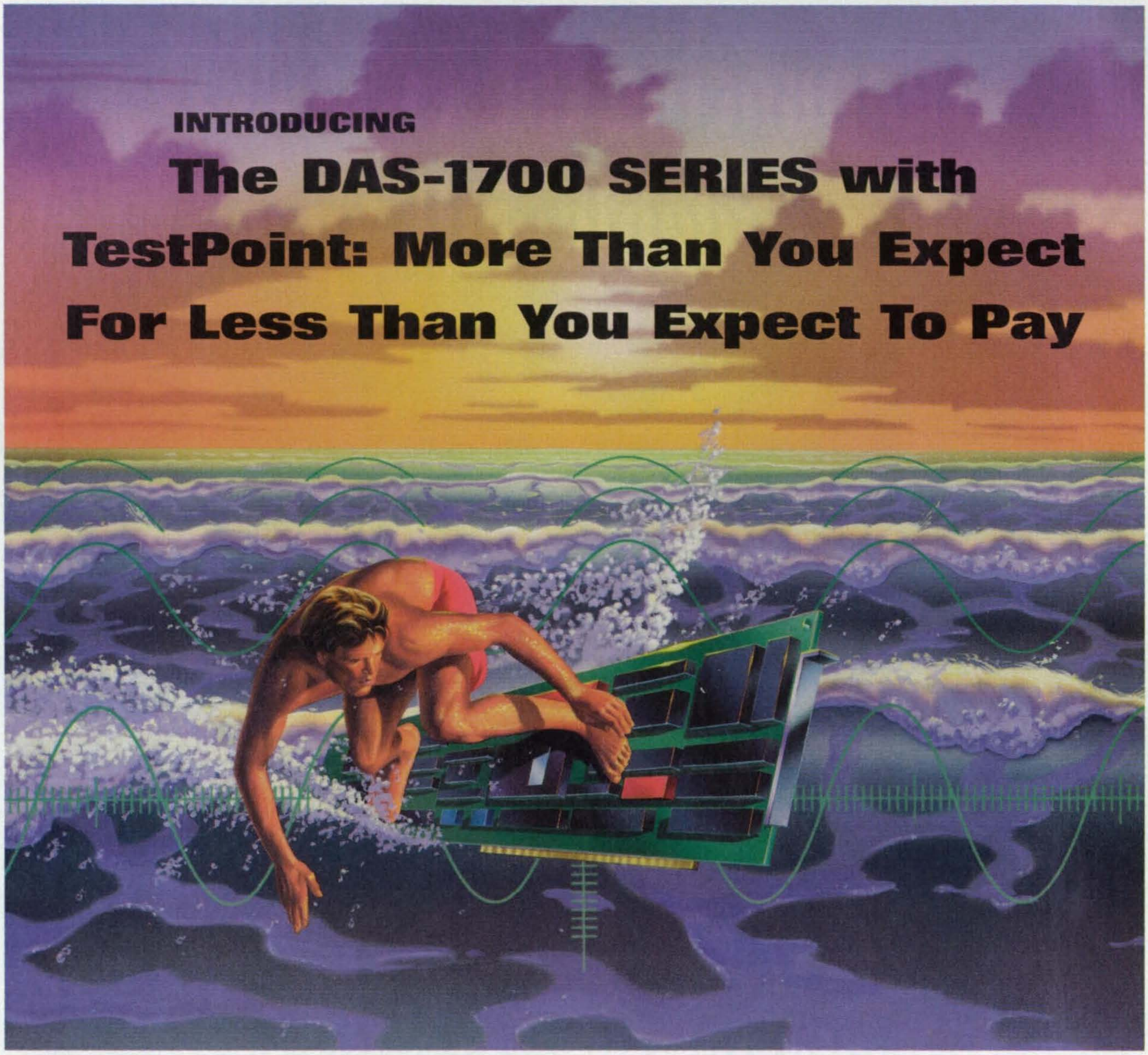

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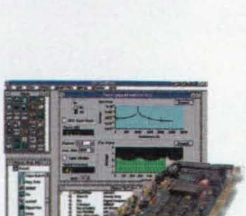

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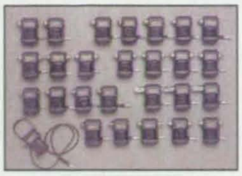
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Aerospike Controller Test System

This is a relatively inexpensive electronic system for testing hardware on a research aircraft.

Dryden Flight Research Center, Edwards, California

Figure 1. This **Artist's Rendering** (courtesy of Lockheed) shows an SR-71A airplane with a half-span, tenth-scale working model of the Linear Aerospike engine mounted at the tail.

The Aerospike Controller Test System is a versatile, modular digital/analog electronic system that has been designed for use in testing aircraft hardware and software for the Linear Aerospike SR-71 Experiment (LASRE) and that is also adaptable to other aircraft-testing projects. The LASRE demonstrates the Linear Aerospike rocket engine, which is a candidate for use in future reusable launch aerospace vehicles: For this purpose, a 10-percent-scale, half-span model of a reusable launch vehicle containing a working scale model of the Linear Aerospike engine is mounted on a modified NASA SR-71A Blackbird airplane (see Figure 1).

The system includes an inexpensive multiprocessor, UNIX-based computer workstation that runs various simulation mathematical models, controls input and output (I/O), and controls a monitor that displays a simulated cockpit control panel. The system also provides power, protection, and signal conditioning for all connections to aircraft hardware.

The primary aircraft component under test is the LASRE controller — a device that controls the flow of fuel and coolant to the experimental Linear Aerospike engine. The LASRE controller requires a combination of analog and discrete signals, a stream of digital signals in RS-422 standard format, and a stream of pulse-code-modulated (PCM) signals to operate.

The system (see Figure 2) includes an I/O subsystem housed in a Versa-Module Eurocard (VME) chassis. The I/O subsystem contains off-the-shelf circuit cards that function as digital-to-analog converters (DACs), receive input discrete signals, and transmit output discrete signals. The signals handled by these circuit cards are simulated versions of the signals produced by experiment sensors, experiment valves, motor clutches, and cockpit controls. A serial data stream in RS-422 format is also used to communicate with the aircraft hardware. An RS-232-to-RS-422 converter is used to convert the RS-232 stream coming from the VME chassis.

The DACs are used to simulate the experiment sensor pressure and temperature signals. These signals are inputs to the PCM subsystem to communicate sensor information to the LASRE controller. The simulation system decommutates the PCM stream to obtain data on the health and status of the LASRE controller.

The simulation system is designed to be modular to provide for rapid reconfiguration. This feature makes it possible to replace software models with real aircraft components. This capability was demonstrated when there arose a need to include an Allied Signal controller in the simulation system.

The cockpit displays and controls are presented to a technician or operator on the monitor, which is housed in an equipment rack. The UNIX workstation that serves as the system simulation computer can be used as a dedicated platform to develop various software scripts for test procedures. The scripts make it possible to automate testing.

The use of a desktop computer workstation and off-the-shelf interface cards makes it possible for this system

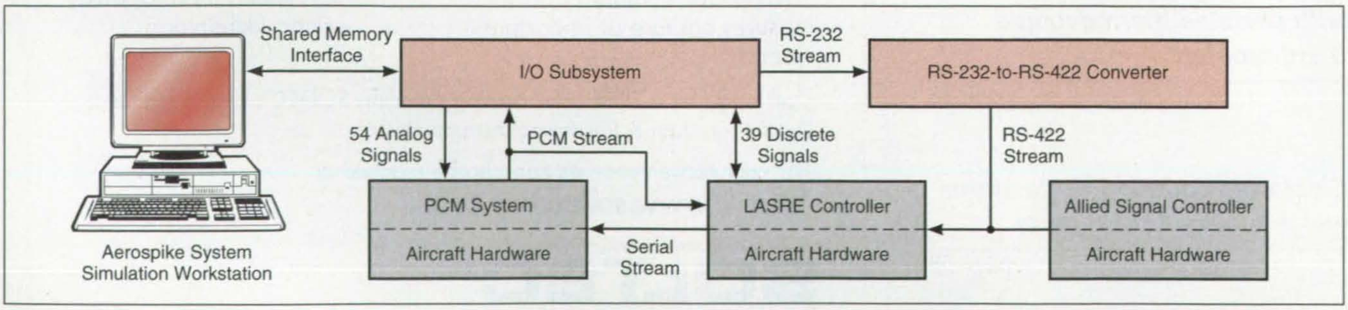

Figure 2. The **Aerospike Controller Test System** is a "hardware-in-the-loop" system that makes the testing, validation and verification of modifications, and improvements to the aircraft hardware simpler and less expensive than they were in previous aircraft projects. With its reduced cost, this system offers an opportunity for utilization of advanced testing techniques in future projects that are constrained by low budgets.

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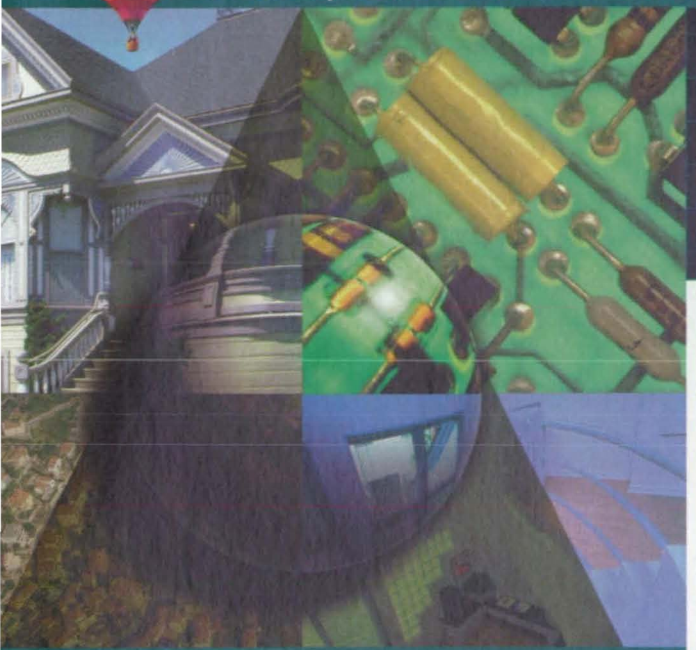

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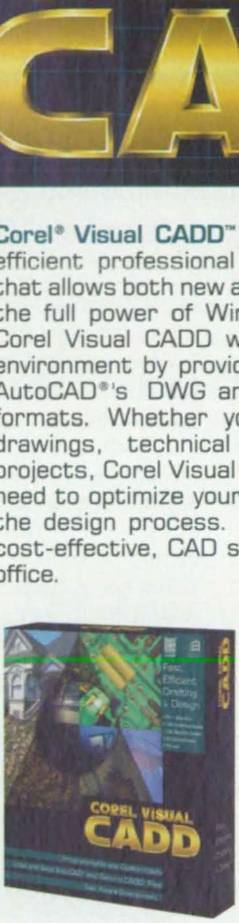

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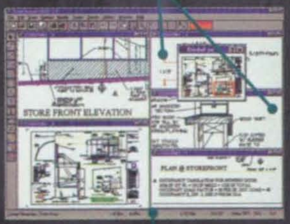

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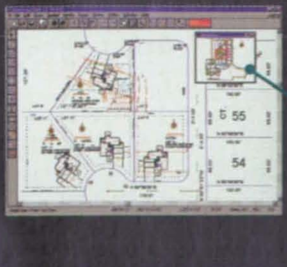

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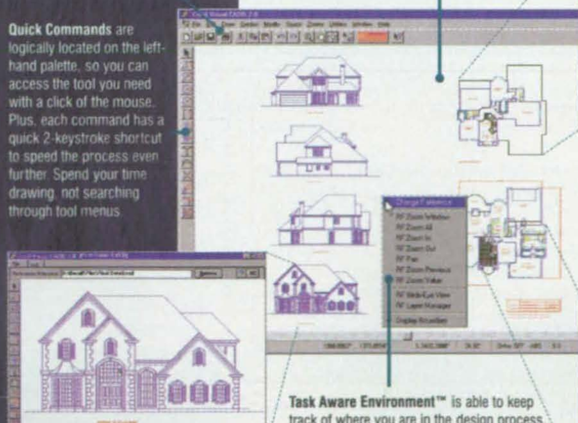

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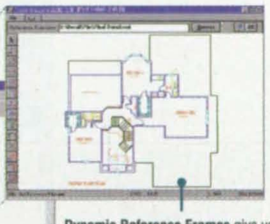

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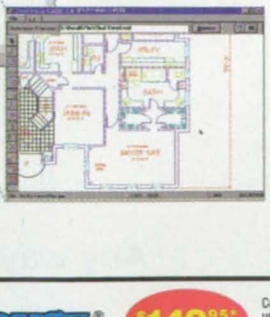

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to be contained entirely within one 6-ft (1.8-m)-tall equipment rack. This compactness affords portability, making it possible to use the system at the research airplane as well as in a laboratory environment. Previously, a system of this type would have included a separate simulation computer, an interface/signal-conditioning equipment rack, and an aircraft hardware rack.

This work was done by Gary V. Kellogg and Ken A. Norlin of **Dryden Flight Research Center.** *No further documentation is available.*
DRC-96-54

Measuring Depths in ICs Using α-Particle-Induced Upsets

Upsettable test SRAMs are incorporated into ICs to measure α-particle penetration.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of determining the thicknesses of metal and other overlayers on integrated circuits (ICs) has been derived from recent developments in the use of static random-access memory (SRAM) ICs as ionizing-radiation sensors. Heretofore, such thicknesses have been measured, variously, by cross-sectioning (which is time-consuming) or ellipsometry (which requires specimen areas larger than typical integrated-circuit features). The present method takes less time than sectioning does, and can be used on specimen areas smaller than those required for ellipsometry.

As a prerequisite to use of this method, a SRAM that is upsettable (susceptible to ionizing-radiation-induced changes in its binary logic states) must be incorporated to an IC as an integral part during design and fabrication. A SRAM of the type used in this method is composed of traditional six-transistor, two-inverter cells, with a total memory capacity of 4KB. The figure presents schematic cross sections of the two inverters.

In preparation for a test according to this method, zeros are written into all the cells of the SRAM, then the SRAM is biased (as explained below) to obtain the specified degree of susceptibility to upset. During the test, the IC is exposed to a beam of energetic α particles. As they pass through the IC, energetic α particles create hole/electron pairs. If enough hole/electron charge is deposited in the layer labeled "collection layer" in the lower inverter in the figure, the memory cell becomes upset. At the end of the test, the SRAM

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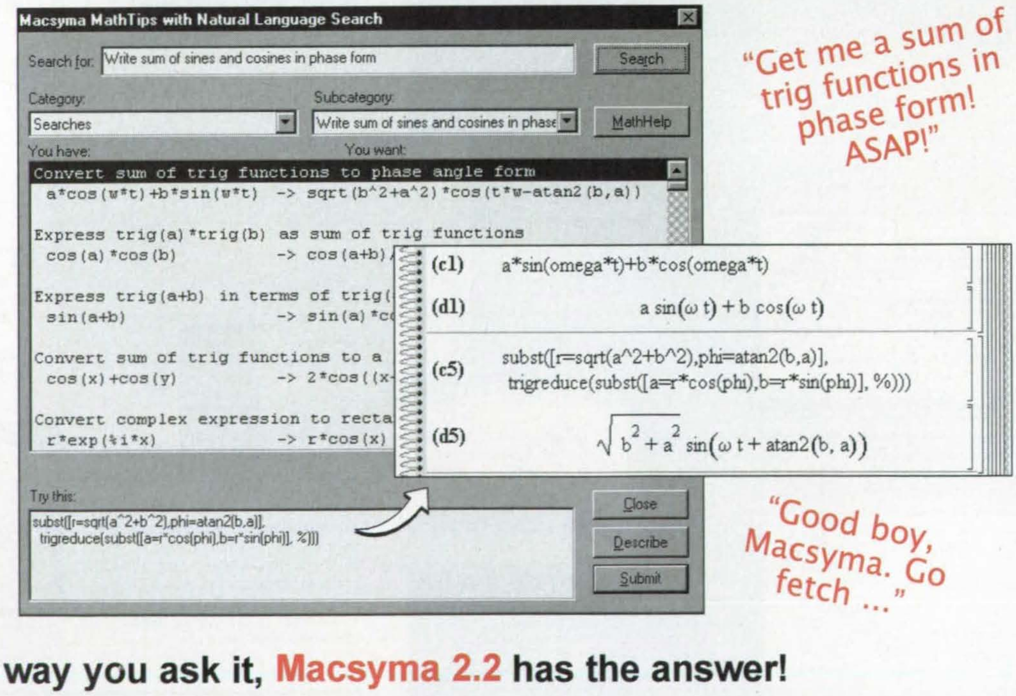

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Express trig(a+b) in terms of trig(
 sin(a+b)               -> sin(a)*c

Convert sum of trig functions to a
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Convert complex expression to recta
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```
(c1)    a*sin(omega*t)+b*cos(omega*t)
(d1)                a sin(ω t) + b cos(ω t)
(c5)    subst([r=sqrt(a^2+b^2),phi=atan2(b,a)],
         trigreduce(subst([a=r*cos(phi),b=r*sin(phi)], %)))
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(d5) $\sqrt{b^2 + a^2}\,\sin(\omega\, t + \mathrm{atan2}(b, a))$

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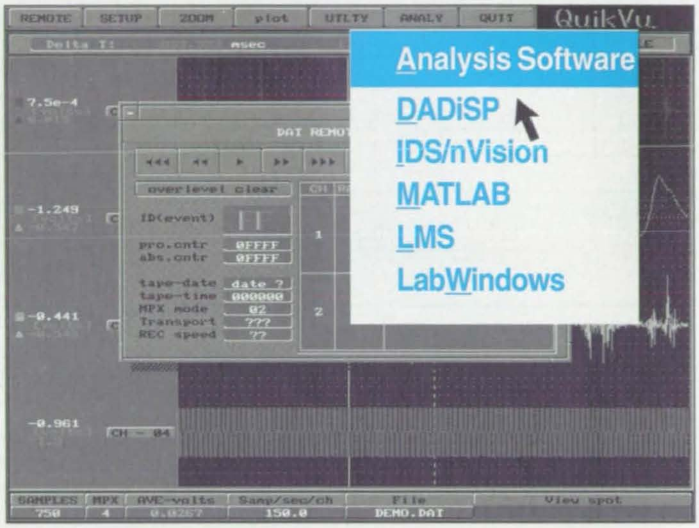

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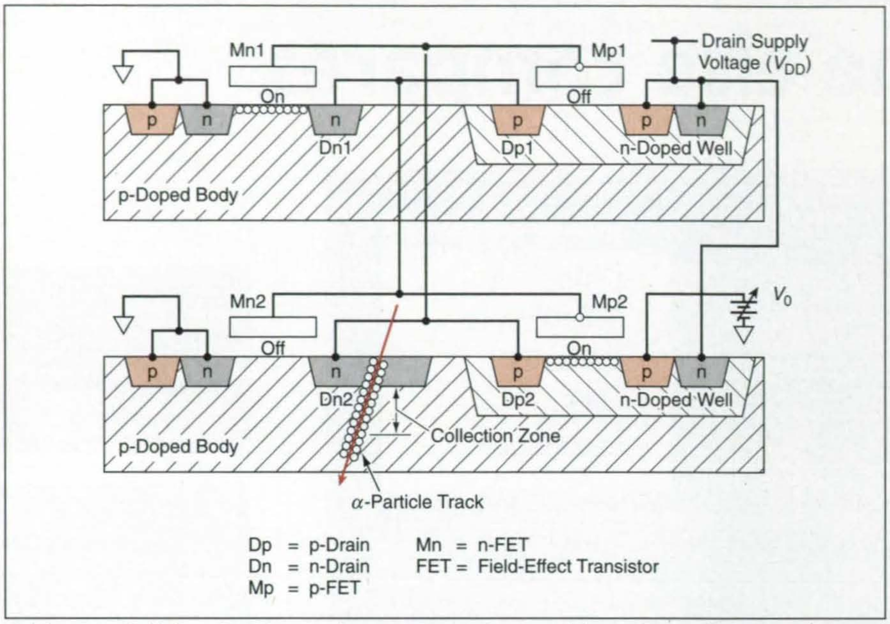
cells in which upsets have occurred are counted to obtain statistical measures of radiation doses. Inasmuch as the radiation doses depend partly on absorption of radiation in (and thus thicknesses of) overlying layers, the measurement data can be inverted to estimate the thicknesses, provided that calibration data have been acquired for SRAMS of the same design with known overlying materials of known thicknesses.

In using a SRAM as a radiation sensor, one exploits a metastable state that lies between two stable states of a flip-flop circuit, these stable states corresponding to binary logic states. The upset behavior of the cell can be characterized partly by an offset voltage connected to the upper inverter in the figure. The susceptibility of the cell to upset can be adjusted by biasing the upper inverter relative to the metastable state; when the bias places the state of the cell close to the metastable state, an α or other ionizing particle that creates a small amount of charge in the collection zone can upset the cell.

This work was done by Martin G. Buehler, George A. Soli, and Melvin Reier of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 66*** *on the TSP Request Card.*
NPO-19611



A **Memory Cell Can Be Upset** when an energetic α particle excites sufficient numbers of electrons and holes in the collection zone under the drain marked "Dn2."

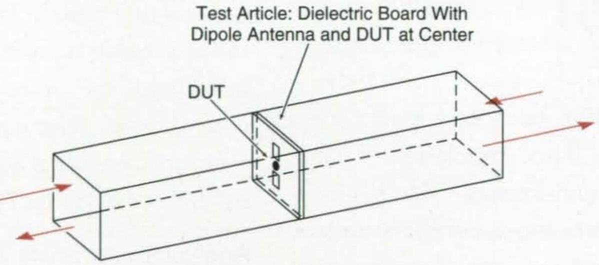
Device Deembedding From Waveguide Simulator Test

Scattering parameters of a device in a planar array are determined by measurement and computation.

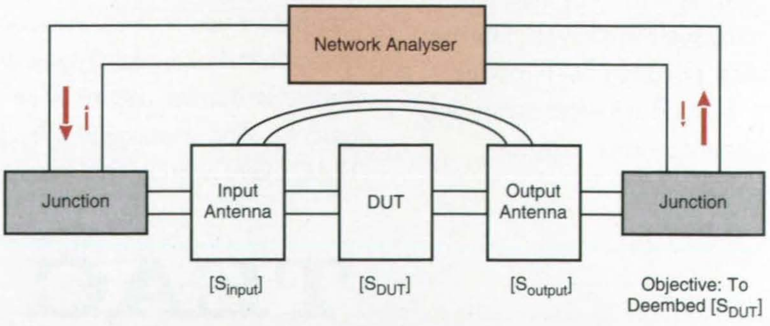
NASA's Jet Propulsion Laboratory, Pasadena, California

A method that combines measurements in a novel microwave testing apparatus and computational simulations has been devised for determining the microwave-scattering parameters of a single electronic device. The device may also be applied to a subassembly of devices in a quasi-optical periodic planar array of such devices. An array of the type in question would typically be a grid amplifier (also denoted an amplifying grid array), in which the unit cells of the periodic array would contain amplifiers, antennas, and other circuit elements.

In general, the determination of electrical characteristics of a device under test, as though these characteristics could be measured in situ with nonperturbing probes, is called "deembedding." The present method of deembedding is made possible by (1) recent advances in techniques for numerical simulation, including contributions to a generalized scattering-matrix technique that make it possible to mathematically separate the scattering matrix of a device under test (DUT) from the scattering matrix of a test article that con-



TEST ARTICLE IN WAVEGUIDE



SCHEMATIC DIAGRAM OF WAVEGUIDE SIMULATOR TEST AND DEEMBEDDING VIA GENERALIZED SCATTERING MATRICES

A **Single Device Is Tested** in a waveguide simulator to determine the microwave scattering parameters of the device.

tains the DUT; and (2) the insight that generalized scattering matrices like those applied to periodic planar arrays could also be adapted to waveguides.

The experimental part of the present method involves measurements of scattering characteristics in an apparatus, called a "waveguide simulator," that includes a square-cross-section waveguide with orthomode junctions at its ends. The DUT is not mounted in the array in which it would ordinarily operate and is not connected to a microstrip, slot, or coplanar transmission line, but to the radiating dipole elements to which it would be connected in the array. For a one-port measurement, the DUT is mounted at the center of a small dipole patch antenna on a dielectric board at the midplane of the waveguide (see figure). By suitable mathematical modeling, the scattering characteristics measured with a single DUT in this apparatus can be related to those of an infinite periodic planar array of identical devices.

The scattering matrices of the orthomode junctions are determined experimentally. A numerical simulation is performed to obtain the scattering matrix of the unit cell of the periodic planar array defined by the dielectric board, including the port where the DUT is placed. Then the scattering parameters of the DUT can be determined from the scattering parameters measured at the external ports of the orthomode junctions. Although a one-port device is shown, the method has also been used to find the scattering parameters of two-port devices. For example, the scattering parameters of a differential pair high-electron-mobility transistor (HEMT) were measured. Such a differential pair is commonly used in grid amplifiers.

This work was done by Larry W. Epp of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 63*** *on the TSP Request Card.*
NPO-19554

Cryogenic System for Testing Microwave Electronic Devices

Tests can be performed at temperatures down to 37 K.

Lewis Research Center, Cleveland, Ohio

The figure shows a system of laboratory equipment, called the "CryoProbe Station," for automated testing of transistors, integrated circuits, and other devices that are designed to operate at microwave frequencies and at low temperatures. The system includes a cryogenic probe fixture, which provides nearly direct electrical connections between each device under test and external test equipment, eliminating the need for wire bonds or special test fixtures that could interfere with measurements. The cryogenic probe fixture includes a stage of 1 by 2 in. (2.54 by 5.08 cm), which is large enough to simultaneously hold both calibration samples and circuits to be tested.

The cryogenic probe fixture is located in a vacuum chamber. Commercial microwave probes with flexible tips are used to make contact with devices on the stage. The probes are mechanically connected, via couplings sealed by metal bellows, to manipulator mechanisms outside the vacuum system; these mechanisms are capable of positioning the probes with a resolution of 0.1 mil (0.0025 mm) anywhere over the stage. The vacuum chamber is equipped with windows, and a zoom stereoscopic microscope is provided for viewing the devices and probes through the windows to guide positioning of the probe tips.

The stage is made of a block of copper and is mounted on a cooling head. Both the stage and the cooling head are equipped with silicon temperature sensors. In operation, the chamber is evacuated, then liquid nitrogen or liquid helium is introduced into the cooling head. The minimum temperature achievable with liquid nitrogen or helium is 80 or 37 K, respectively. By use of a small heater and an external temperature-control circuit connected to the temperature sensors, the temperature of the stage can be stabilized to within 0.2 K of a set value slightly above the minimum achievable temperature.

The external test equipment operated in conjunction with this system could be, for example, an automatic network analyzer or a noise-figure meter. The system with an automatic network analyzer has been used to measure the S-parameters (transmission and reflection coefficients indexed to input and output ports) of high-electron-mobility transistors (HEMTs) and of


OVERALL SYSTEM

CHAMBER

The **CryoProbe Station** is a laboratory system that provides low temperature and electrical connections for testing microwave electronic devices.

circuits containing field-effect transistors and transmission lines, at frequencies from 0.045 to 26.5 GHz. The system with a noise-figure meter has been used to measure the frequency dependence of noise in HEMTs at a temperature of 77 K as well as at room temperature.

This work was done by Susan Reinecke, Samuel A. Alterovitz, Ben T. Ebihara, and Robert R. Romanofsky of **Lewis Research Center** *and Paul G. Young of the University of Toledo. For further information,* ***write in 30*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Rd., Cleveland, OH 44135. Refer to LEW-16312.

Laboratory Portable Infrared Reflectometer

The size of the surface to be characterized is not limited.

Marshall Space Flight Center, Alabama

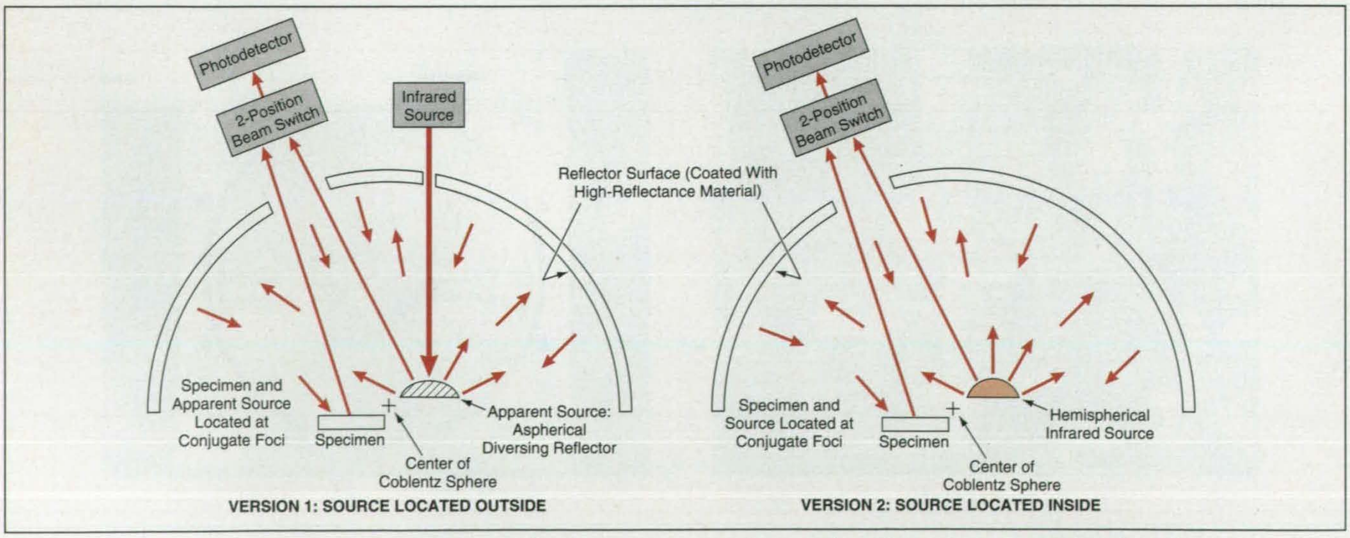
The figure illustrates the laboratory portable infrared reflectometer (LPIR) for measuring the directional-hemispherical infrared reflectance and thermal radiative properties of large and small surfaces. The LPIR is based on a combination of (1) the same basic measurement principle as that of older laboratory instruments that contain 2π steradian reflectors and are used to measure total hemispherical reflectances and (2) the optical properties of the Coblentz sphere, which has long been used in measuring total integrated scatter.

Conventional instruments cannot be used to characterize a large surface unless small specimens are cut from the surface or witness samples are prepared. This is because the optical design of the instrument demands a specimen that fits within a small area. The most important advantage of the Coblentz sphere is that the specimen is placed slightly outside of the instrument, so that there is not any limit on the size of the surface that can be surveyed; the specimen can be a small area on a large surface, the instrument can be brought to the surface, and there is no need to cut small specimens from the surface.

The inner surface of the dome of the LPIR is a spherical concave imaging reflector. Unlike a traditional Coblentz sphere, this reflector is not used to collect light scattered from the specimen; instead, its imaging function is to evenly focus infrared light from a source (or an apparent source) onto the specimen from all angles. For this purpose, it is necessary to place the specimen and the source (or apparent source) at conjugate foci of the reflector. In general, conjugate foci of a concave spherical reflector are located equal distances in opposite directions slightly off the center of the sphere. In the case of the LPIR, the foci are chosen so that the source (or apparent source) of light is located at one focus slightly to the right of center and slightly above the rim of the reflector dome; the other focus, where the specimen must be placed, is slightly left of center and slightly below the rim.

In the version of the LPIR shown in the left part of the figure, a beam of infrared light is generated outside the reflector dome and aimed into the dome through a small opening onto a small fourth-order-aspherical diverging reflector located at one of the foci. Thus, the apparent source of light is approximately a point source located at the focus inside the small diverging reflector. This diverger is designed to work in conjunction with the sphere so that the sample is evenly illuminated from all angles within 2π steradian. In the version of the LPIR shown in the right part of the figure, the source of infrared radiation is a tungsten/halogen lamp with a hemispherical quartz envelope that is painted with a high-temperature ceramic gray-body coating. Note that this allows a full 2π steradian to be collected as compared to a much smaller angle (0.1π steradian) in the other setup.

The light from the source or apparent source illuminates the reflector uniformly, and the reflected light illuminates the specimen. Through a small opening near the top of the reflector dome, a photodetector alternately measures light reflected from the specimen and light emitted by the source (or apparent source). The photodetector and its optics are carefully sized such that the projected measurement area at the surface of the sphere is the same for both measurements. The total hemispherical reflectance, ρ of the specimen is then



The **Laboratory Portable Infrared Reflectometer**, the Coblentz sphere allows large and small samples to be measured.

given $\rho = I_{SPECIMEN}/(I_{SOURCE}\rho_{REFLECTOR})$, where $I_{SPECIMEN}$, and I_{SOURCE} denote the photodetector readings during the specimen and source measurements, respectively, and $\rho_{REFLECTOR}$ denotes the known reflectance of the imaging reflector.

This work was done by Donald R. Wilkes, John S. Harchanko, and Edgar R. Miller of AZ Technology, Inc., for **Marshall Space Flight Center**. *For further information,* ***write in 28*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-26326.

Technique for Measuring Microwave Surface Conductivities

An automatic network analyzer is used in conjunction with a resonant cavity.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved technique for measuring the surface electrical conductivities of materials at microwave frequencies is derived from an older technique that involves measurement of the magnitude of the transmission-coefficient scattering parameter (S_{21}) at and near the frequency, f_r, of the TE_{011} resonant mode of a round cylindrical microwave cavity. The need for this technique arises in connection with analyzing the dissipative losses of microwave waveguide and antenna components made of various materials. Because surface conductivities at microwave frequencies differ from those at dc and can be affected by surface finishes and surface chemical treatments, it is necessary to measure the surface conductivities in the frequency ranges of the intended applications.

In the improved technique as in the older technique, one of the two end surfaces of the cavity is covered with a plate specimen of the material of interest (see Figure 1). Then $|S_{21}|$ is measured as a function of frequency. From the measurement data, one determines the frequency of minimum insertion loss (maximum $|S_{21}|$) and the frequencies at which $|S_{21}|$ is 3 dB below the maximum. Nominally, the frequency of maximum $|S_{21}|$ is f_r. From these frequencies, one determines the resonance quality factor (Q) of the cavity.

The Q increases with the sharpness of the resonance peak; that is, it increases with the ratio between f_r and the difference between the 3-dB frequencies. Q is related in a known way to the surface conductivity of the specimen, and the surface conductivity of the specimen can thus be determined from the effect of the specimen on Q.

In the older technique, the measurements of $|S_{21}|$ vs. frequency were performed manually. Because of frequency drift and jitter, the frequencies of the 3-dB points could not be measured to a resolution finer than 1 kHz. In the improved technique, the 3-db points are measured to a resolution of 0.1 kHz due to rapid measurements and averaging performed through the use of an automatic network analyzer under computer control; as a result, the Q is measured more accurately. On command, the apparatus finds the frequency of maximum $|S_{21}|$ and the 3-dB frequencies and generates a video display and/or a printout of a plot of $|S_{21}|$ vs. frequency (see Figure 2).

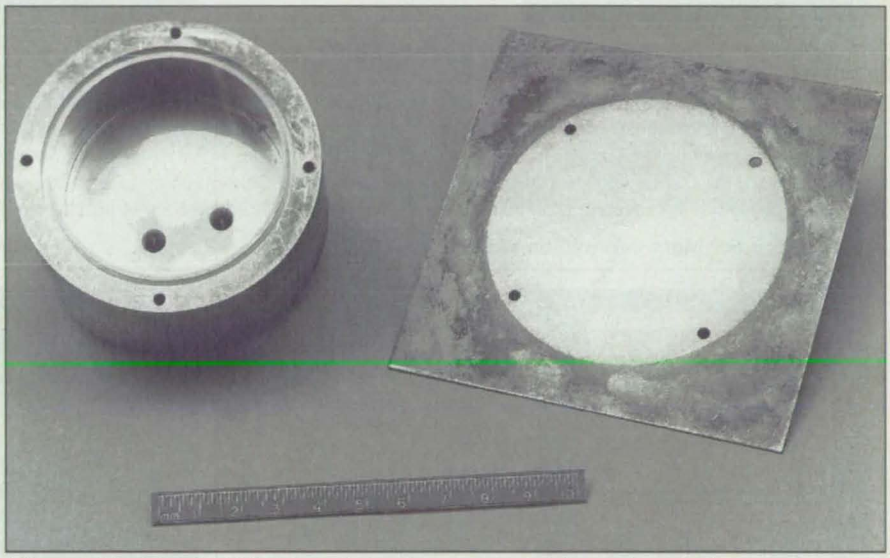


Figure 1. **The Specimen Is Placed** over the open end of the cavity, and the measurements and calculations described in the text are performed. The cavity is nominally resonant at 8.420 GHz.

This work was done by Tom Y. Otoshi and Manuel M. Franco of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 4*** *on the TSP Request Card.*
NPO-19752

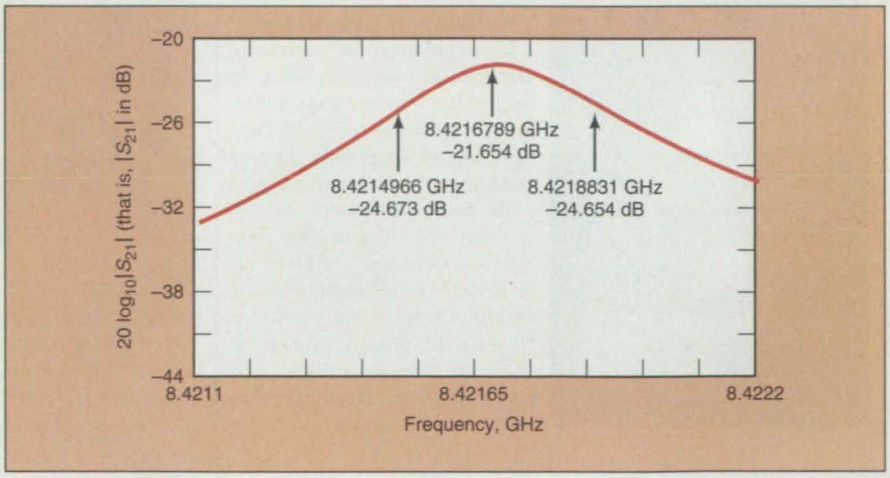


Figure 2. This **Plot Was Obtained From Measurements** taken with a copper specimen covering the opening in the cavity.

Test & Measurement

Spatial Positioning Systems, Reston, VA, has introduced the Odyssey **position measurement system**, which incorporates the Odyssey 3D coordinate measurement instrument with environmental sensors for environmental engineering surveys and robot vehicle tracking within hazardous areas. It can be integrated with many commercial instruments.

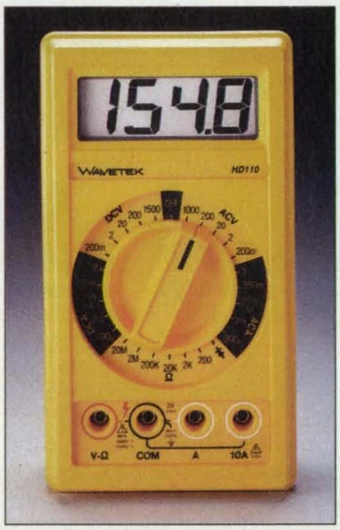
The handheld measurement wand can guide the user to points where instrument sensor readings must be taken. Once at the point, the user activates the data collector to capture the output from the instrument. The system automatically tags the sensor output with the 3D coordinate of the sensor's position. The system uses stationary laser transmitters and mobile optical receivers to instantly measure and record the data. Captured data can be displayed using a 3D CAD model or graphically using computer software.

For More Information Write In No. 735

Sierra Instruments, Monterey, CA, has introduced the Mass-Trak **flow controller**, which measures and controls gas mass flow rates. An integrated proportional control valve provides one-step control of critical gas flows. The controller can be used as a replacement for volumetric flow measurement devices that are sensitive to changes in operating temperature and pressure.

The unit's on-board display and set point control eliminate the need for separate power supply and readout electronics. It is available for flow rates up to 50 standard liters per minute and features a large-diameter straight sensor tube to prevent clogging and contamination. Control accuracy is ±1.5% of full scale.

For More Information Write In No. 736



The Model HD110 **digital multimeter** from Wavetek, San Diego, CA, is drop-proof and water/splash-proof, allowing operation outdoors in any environment. The unit features 1500-hour battery life, a measuring range of 1500 VDC 1000 VAC and AC/DC current to 10A. It measures resistance to 20 MΩ and has 6 kV transient overload protection.

The over-sized display has 0.8" characters, allowing users to read results at a glance. The handheld unit features diode and continuity testing, and 0.1% accuracy. It is priced at $219.95.

For More Information Write In No. 737

MTS Systems Corp., Eden Prairie, MN, has announced the TestStar™ IIs digital servohydraulic **test control system** for general materials and component testing applications in the microelectronics, materials, biomechanics, aerospace, automotive, and laboratory areas. The control system covers a range of testing requirements, from monotonic testing such as tensile and flex, to complex tests such as fatigue, fracture mechanics, and service history simulation.

The system incorporates a single-channel, single-station controller and a personal computer with Basic TestWare®, an application that enables users to configure and run simple tests. Optional MultiPurpose TestWare software is available for creating and running a variety of test programs. The system software runs on Windows NT, providing compatibility with common software for data display, analysis, and management.

For More Information Write In No. 738

Hardy Instruments, San Diego, CA, offers the HI 5701 VT **vibration transmitter**, a two-wire, loop-powered transmitter for measuring vibration on machinery such as pumps, fans, blowers, motors, and mixers. It provides two types of signals: one for the process engineer and one for the vibration analyst.

The transmitter attaches directly to a bearing housing or other measurement point on a machine. It converts the vibration signal from 4 to 20 mA proportional to velocity, allowing the process engineer to trend the vibration using a programmable logic controller or distributed control system.

For More Information Write In No. 739

The 740 Series **documenting process calibrator** from Fluke Corp., Everett, WA, is available with six new pressure modules: the -700PA3, -700PA4, -700PA5, and -700PA6 perform absolute pressure measurements to 100 psi; and the -700PV3 and -700PV4, which provide vacuum measurements to 15 psi. Reading rate for the six modules is 2 per second.

The modules are fully interchangeable and feature internal temperature compensation for full accuracy from 0°C to 50°C. Pressure ranges to 10,000 psi are available. The modules are dirt-, dust-, and moisture-resistant and come with a metric adapter. Fittings are made of 316 stainless steel or Hastelloy C276 and have internal mechanical supports. Pressure readings can be displayed in ten different units, including psi, mmHg, or kPa. The modules are priced at $995 each.

For More Information Write In No. 740

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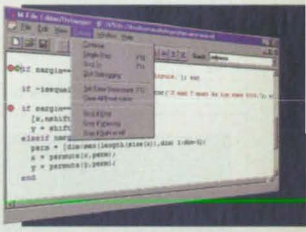

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MATLAB lets you model complex data graphically. Here, lighting effects highlight topography data. Source: NOAA.

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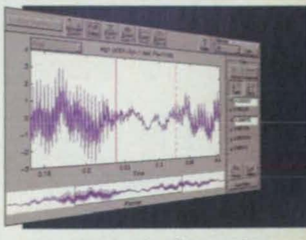

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For More Information Write In No. 520

Test & Measurement

The Model 262 **portable reflectometer** from Dyn-Optics, Laguna Hills, CA, incorporates fiber optics in a probe that is touched to the surface to be measured. The reflectance is then displayed on the digital meter. The instrument is calibrated by inserting the probe into the calibration port and adjusting the calibration potentiometer so that the digital meter indicates 100%.

The instrument measures the reflectance of the surface touched by the probe and can be used on flat or curved surfaces.

For More Information Write In No. 745

Barnant, Barrington, IL, has introduced the I-Safe **thermocouple thermometers** for most portable temperature measurement and monitoring applications. The units feature UL and cUL Intrinsically Safe ratings, and are CE-certified for electromagnetic compatibility. Five instruments are available: three standard models, in Type J, K, or T versions; the Dual Input J-T-E-K, a dual-input, multi-function meter with two-point calibration; and the DuaLogR®, a dual-input temperature logger with infrared data transmission output capable of logging up to 1,000 readings in real time.

All models include a calibration lock-in feature to prevent tampering. The units feature impact-resistant ABS/polycarbonate cases with built-in stands and sealed silicone rubber keypads. They are IP-54 rated for splash and dust resistance.

For More Information Write In No. 742

The Super Count™ electronic **counting scale** from Setra Systems, Boxborough, MA, comes with a built-in memory capable of storing up to 256 part numbers, their associated average piece weight, and the tare weight of the containers. The scale employs a patented variable capacitance technology to provide an internal counting resolution to 1 part in 500,000.

The scale can distinguish incremental weights as small as 0.0002 percent of capacity. It is available in seven weighing capacities from 2.2 to 110 lbs. and features a multi-function keyboard that allows users to enter up to 12 fields of data, including part number, lot number, time and date, tare weight, and APW for record-keeping. Other features include selectable accuracy from 95 to 99.99%, overload protection, optional 30-hour battery, and supervisory controls.

For More Information Write In No. 743

Dwyer Instruments, Love Controls Div., Michigan City, IN, has introduced the Series IR **infrared thermometer** for measuring the temperature of hard-to-reach, hazardous, or moving materials. The noncontact unit can be used for troubleshooting, preventative maintenance, quality control, or early detection of heat problems in machinery and equipment. It is trigger-operated and features a distance-to-target size ratio of 8:1.

Three models are available with accuracy of ±2% of reading and repeatability of ±1% of reading. The standard Model IR 100 measures temperatures from -20 to 400°C and features display hold. Emissivity is fixed at 0.95 to measure concrete, asphalt, rubber, and oxidized materials. Models IR210 and IR211 measure temperatures from -20 to 500°C and feature adjustable emissivity. All models are battery-operated, measure 5.3" x 1.0" x 7.7", and weigh 9.5 ounces.

For More Information Write In No. 744

Cole-Parmer Instrument, Vernon Hills, IL, offers an **electronic flowmeter/accumulator**, which features integral display with accumulation. A rotating turbine detector generates an electronic signal, which is transformed into a six-digit readout. The meters are available with four different housing materials to accommodate most corrosive fluids.

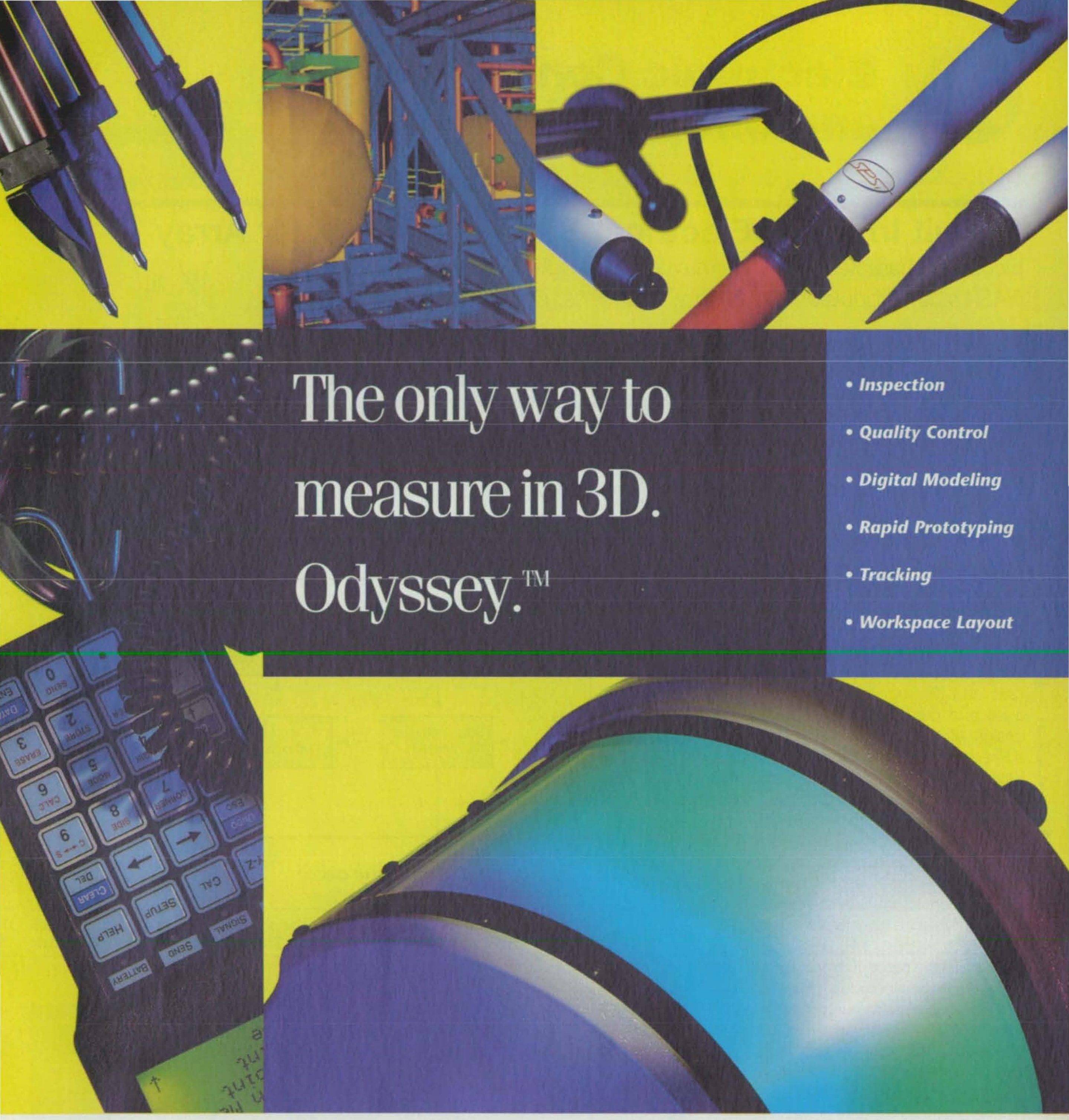
The meters have an average battery life of 2000 hours and are replaceable. Optional equipment includes nozzles, hose assemblies, and calibration containers.

For More Information Write In No. 741

Tegam, Geneva, OH, has introduced the SG5050 2.5 Ghz leveled sine **wave generator** for automated scope calibration applications in the TM5000 format. It is compatible with most lab and calibration software, including Met/Cal, Sure Cal, and LabVIEW.

Users may upgrade existing TM5000 scope calibrators by plugging in the SG5050 unit, which is compatible with existing TM5000 mainframes and plug-ins. Existing automated scope calibration capability can be increased with leveled sine wave generation to 2.5 GHz.

For More Information Write In No. 746



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For More Information Write In No. 695

Electronic Components and Circuits

Circuit Imitates Electrical Behavior of a Solar Array

Electrical characteristics are simulated with high fidelity.

NASA's Jet Propulsion Laboratory, Pasadena, California

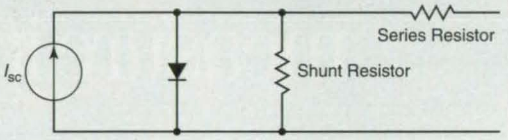
An analog circuit imitates the dynamic electrical behavior of a solar photovoltaic array with high fidelity over a wide range of insolation levels. The circuit can serve as a simulated solar array for testing equipment that is designed to be connected to a solar array when the array is not available or cannot be exercised over the full range of required test conditions.

The top part of Figure 1 shows a simple equivalent-circuit model of a solar photovoltaic array. While a circuit like this model can be readily constructed, it is difficult to find a diode that both (1) matches the low impedance of a string of series-connected solar photovoltaic cells and (2) supports the higher voltages and currents of a full array. The design of the present circuit does not utilize such a power diode to obtain the desired electrical characteristics. Instead, the reverse body drain diode of an n-channel enhancement field-effect transistor (FET) is used to generate a small control signal, which is fed to a power stage that can be driven in a manner consistent with the power output of a full solar photovoltaic array.

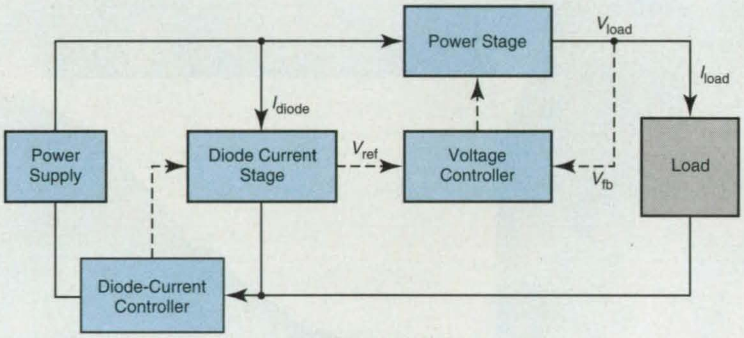
The bottom part of Figure 1 is a block diagram of the present circuit. The diode current stage includes two IRF150 HEXFETs. The source and gate of each transistor are shorted together and the transistors are connected in series (drain of one transistor connected to the source and gate of the other). The body diodes are thus also connected in series.

When there is no load on the circuit, a fixed fraction of the short-circuit solar-array current I_{sc} is forced through the diode current stage to forward-bias the diodes. This current, I_{diode}, is the maximum current that flows through the forward-biased diodes. The resulting voltage, V_{ref}, developed across the body diodes is then used as a reference for the power stage. The power stage is a series pass regulator. The feedback signal, V_{fb}, is adjusted, as needed, to make the no-load (open-circuit) output voltage of this circuit equal the open-circuit voltage, V_{oc}, of the solar array to be simulated.

When a load is present and when the load current (I_{load}) changes, the diode-current controller effects a proportional change in I_{diode}. The resulting change in voltage across the diodes results in a change in V_{ref}, causing the output voltage V_{load} to change. The overall effect of the analog feedback control loops in this



EQUIVALENT-CIRCUIT MODEL OF A SOLAR PHOTOVOLTAIC ARRAY



PRESENT CIRCUIT

Figure 1. The **Present Circuit** electrically imitates a solar photovoltaic array better than does a simple equivalent-circuit model that contains a power diode. Only two input control signals are needed; one to set the V_{oc}, the other to set the I_{sc} of the array.

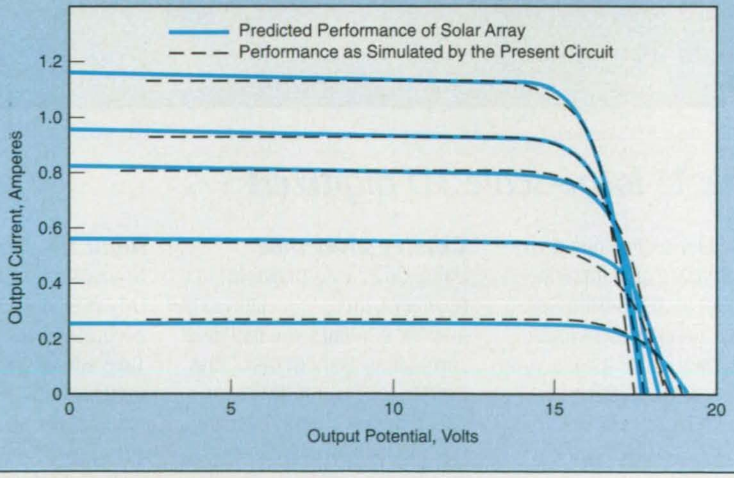
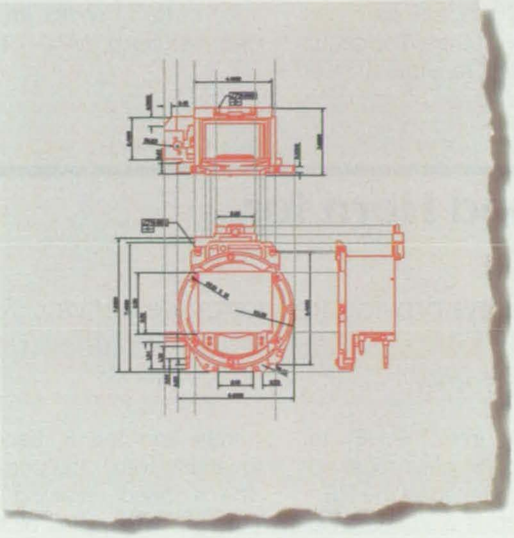
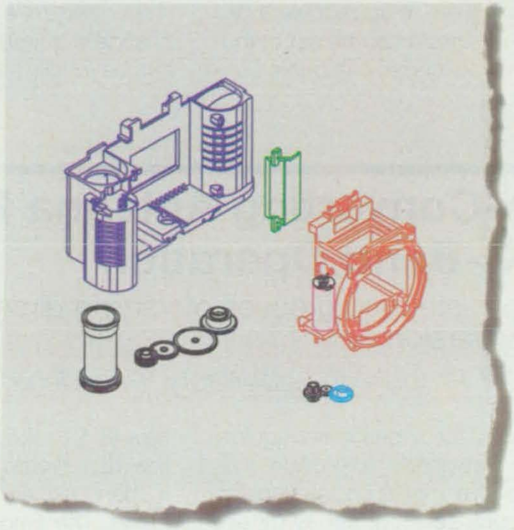


Figure 2. **Current-vs.-Voltage Curves** of the present circuit were found to resemble closely the predicted corresponding curves of an array of 13 strings, each containing 18 GaAs/Ge solar cells. Each pair of the 5 pairs of curves represents the performance of the array at one of 5 levels of reduced insolation.

To anyone who is choosing between designing in 2D or 3D, we offer the following advice.





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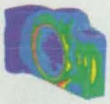

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circuit is to create an output electrical characteristic that closely resembles the current-vs.-voltage output characteristic of a GaAs solar array (see Figure 2).

Only two input control signals are needed to operate this circuit; these are analog signals that represent V_{oc} and I_{sc}. These signals can be set manually or generated under computer control. Once the analog V_{oc} and I_{sc} levels are set, the analog feedback control loops in the circuit govern both the steady-state and transient responses. The transient response of this circuit is quite fast; in the original application, it responded to a half-ampere step load change in a time of < 100 μs. The circuit can be readily adapted to simulation of different solar arrays by scaling the power stage and power-supply functional blocks.

This work was done by James Gittens of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 3*** *on the TSP Request Card. NPO-19749*

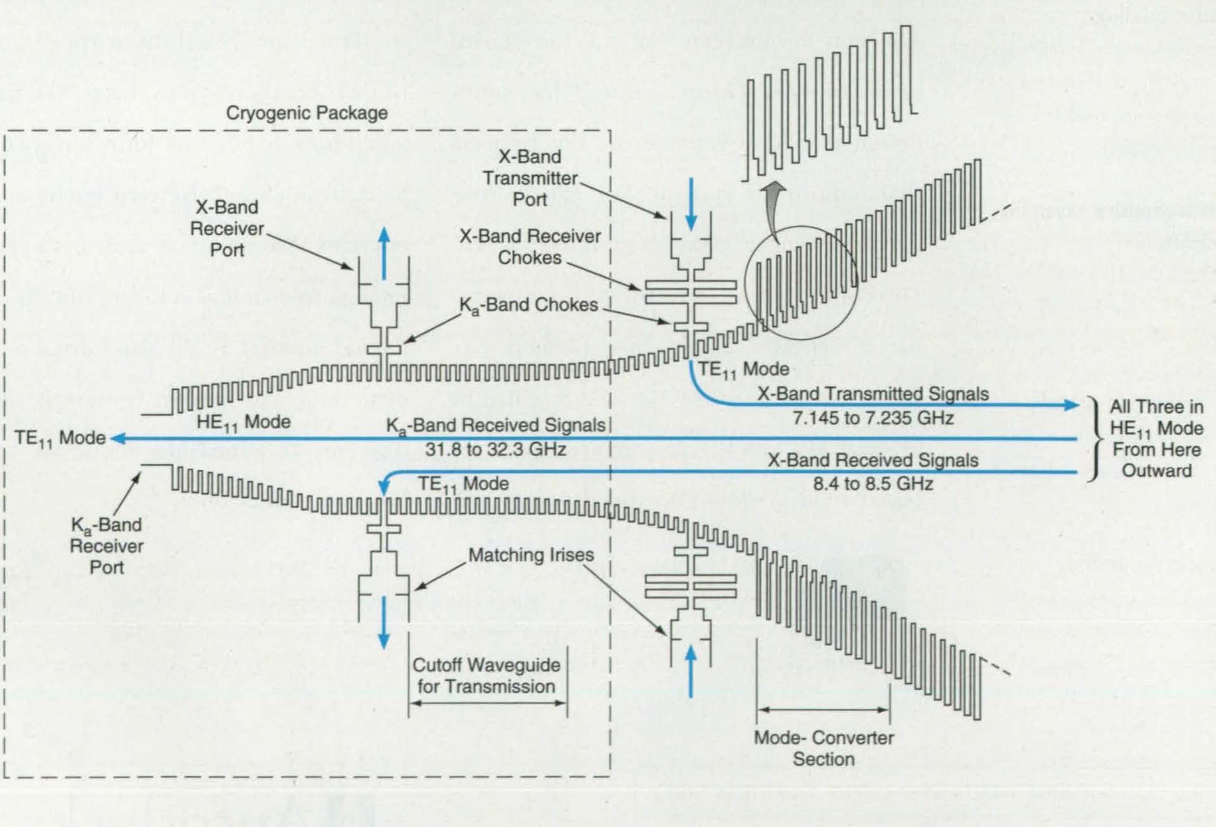
Mode-Converting Antenna Feed Horn for X/X/K_a-Band Operation

Dual-depth-stepped grooves of varying dimensions provide frequency-selective mode conversion.

NASA's Jet Propulsion Laboratory, Pasadena, California

A feed horn for a beam waveguide antenna is designed to provide frequency-selective mode conversion for circularly polarized signals at different frequencies propagating simultaneously in opposite directions. More specifically, the feed horn is designed to (1) convert transmitted X-band signals (at frequencies from 7.145 to 7.235 GHz) from the TE_{11} to the HE_{11} mode, (2) convert received X-band signals (8.4 to 8.5 GHz) from the HE_{11} to the TE_{11} mode, and (3) pass received K_a-band signals unchanged in the HE_{11} mode. The feed horn is also designed to accommodate (1) a cryogenic package for low-noise X- and K_a-band receivers and (2) transmitted power up to 20 kW.

The feed horn has a corrugated, common-aperture configuration, with the input/output ports for two X subbands and the K_a-band at different locations within the common aperture. The K_a-band receiving port is at the throat (narrow) end of the horn; from this end, the horn tapers out to a corrugated straight section that acts as a cutoff waveguide to prevent the X-band transmitted signal from propagating to the receivers. The X-band received signal is extracted from within this straight section.



The **Mode-Converting Feed Horn** features dual-depth-stepped grooves in a novel design in which the widths of the steps taper along the conical flare.

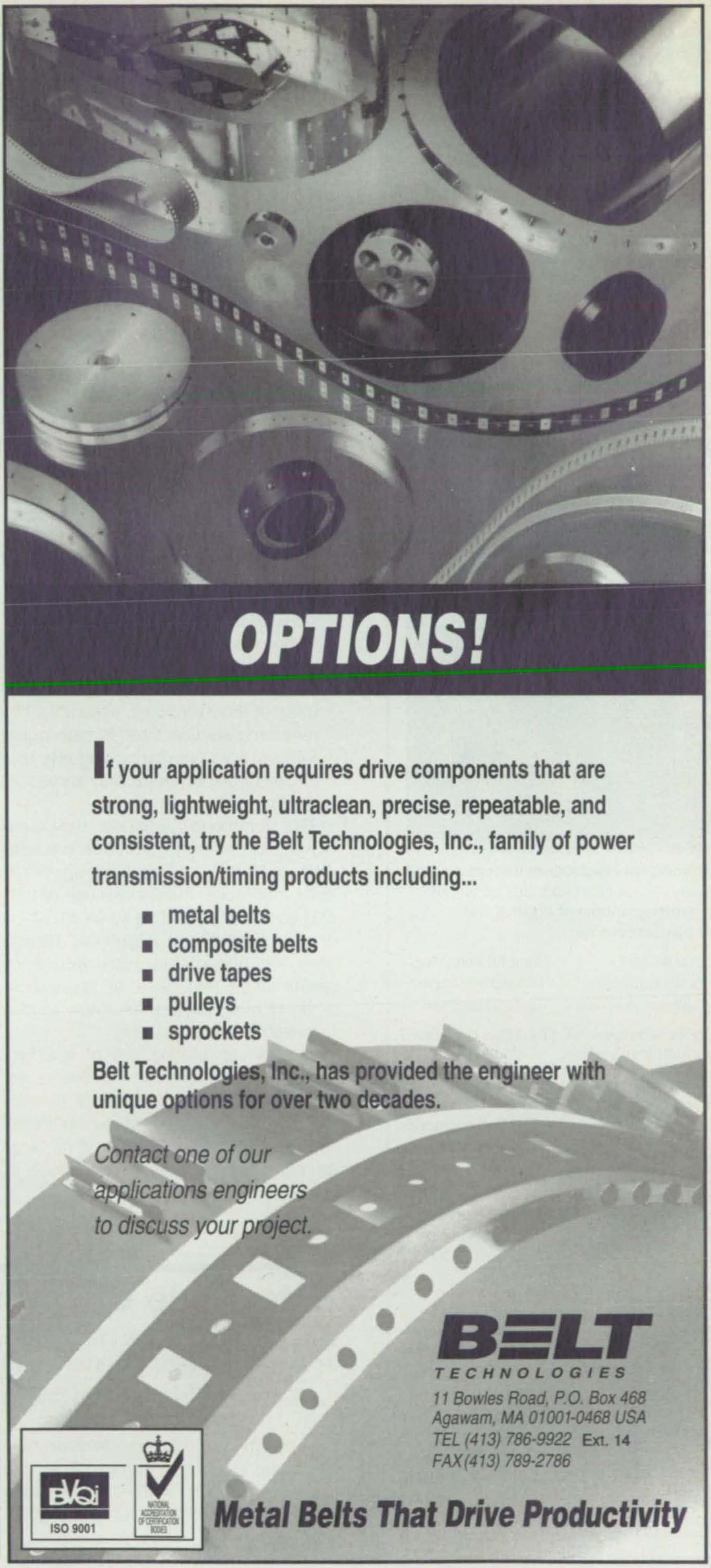
The X-band receiver port comprises a total of four subports in two pairs. The subports within each pair are located diametrically opposite each other, and the two pairs are separated circumferentially by an angle of 90°. The placement of the subports in each pair at diametrically opposite points cancels out the higher-order modes generated at the junction. The 90° angular interval between the pairs of subports is necessary for circular polarization. Each X-band receiving subport includes a matching iris to reduce the return loss, plus a K_a-band choke ring to prevent leakage of the K_a-band signal into the X-band receiver.

Proceeding toward the wider end, the horn tapers in a curved, gradual transition from the straight section out to a conical flare of 14° half angle. The X-band transmitter port, located in the transition region, comprises four subports similar to those of the X-band receiver port. In addition to a matching iris and a K_a-band choke ring, each X-band transmitting subport also includes two X-band receiving chokes.

The corrugations in the waveguide and transition sections described thus far are relatively shallow. They support the HE_{11} mode in the K_a-band and exert very little effect on the X-band transmitted and received signals. Deeper corrugations in the conical flare are designed to effect the desired conversion between the TE_{11} and HE_{11} modes in the X-band without introducing mismatch and without disturbing the HE_{11} mode in the K_a-band. These corrugations are dual-depth-stepped grooves.

The general concept of stepped grooves is not new, but the particular stepped-groove design and its application to frequency-selective mode conversion is novel. Heretofore, periodic stepped grooves with constant dimensions have been used to support the HE_{11} mode in multiple frequency bands. In the present design, the dimensions are not constant: As one proceeds outward along the conical flare, the deeper step in each succeeding groove is slightly wider and the shallower step slightly narrower than in the preceding groove (toward the wide end, the shallower step disappears). This progression of step widths provides the required matched transition and frequency-selective mode conversion for the three frequency bands.

This work was done by Philip Stanton and Jacqueline Chen of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 70*** *on the TSP Request Card. NPO-19907*



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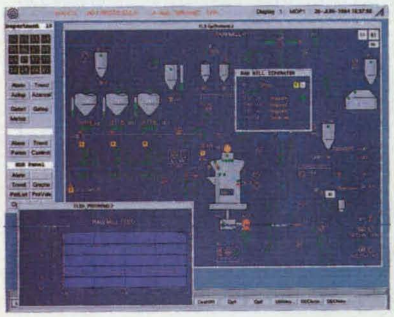

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Antenna/Waveguide Assembly With Separable Sections

Passively transformable microwave assembly performs task of waveguide and three antennas.

NASA's Jet Propulsion Laboratory, Pasadena, California

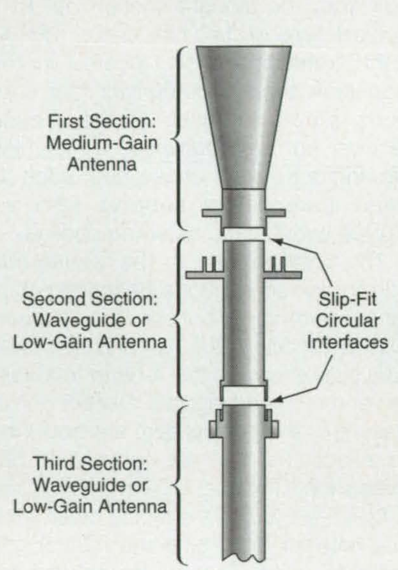
The figure illustrates a circular-cross-section of a three-section microwave antenna/waveguide assembly that allows for seamless, operational transitions through three configuration changes of the Mars Pathfinder Spacecraft/Lander:

1. During cruise to Mars, the first section functions as a medium-gain horn, while the lower two sections act as circular waveguide.
2. Just prior to entry into the Martian atmosphere, the spacecraft cruise stage is ejected along with section one of the microwave assembly. The second section, located on the top of the spacecraft backshell, then functions as a choked waveguide horn.
3. During descent onto Mars, the lander portion drops out of the spacecraft shell, separating sections two and three of the microwave assembly. The remaining section three is then transformed from circular waveguide to a choked horn antenna and serves as the lander low-gain aerial.

The junctions between the three waveguide/antenna sections are specially designed, self-aligning, slip-fit circular interfaces. They make use of ball-and-socket-style mating surfaces, which ensure tight lateral alignment necessary for acceptable radio-frequency performance and ease of separation, while allowing limited free rotary motion between sections.

This design makes use of a single, passively-transformable microwave assembly to perform the task of electromagnetic conduit and three antennas. This simpler, low-cost method replaces an earlier baseline that made use of three separate antennas, two switches, coaxial cables, and cable cutters.

This work was done by Kevin Burke, Joseph Vacchione, and Hugh Smith of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 27*** *on the TSP Request Card.*
NPO-20004



This **Passive Microwave Assembly** is transformed from cruise-stage medium-gain antenna (section one, with section two and three functioning as waveguide), to back-shell low-gain antenna (section one ejected, section two and three functioning as antenna and waveguide, respectively), then to lander low-gain antenna (section two ejected with section three functioning as antenna).

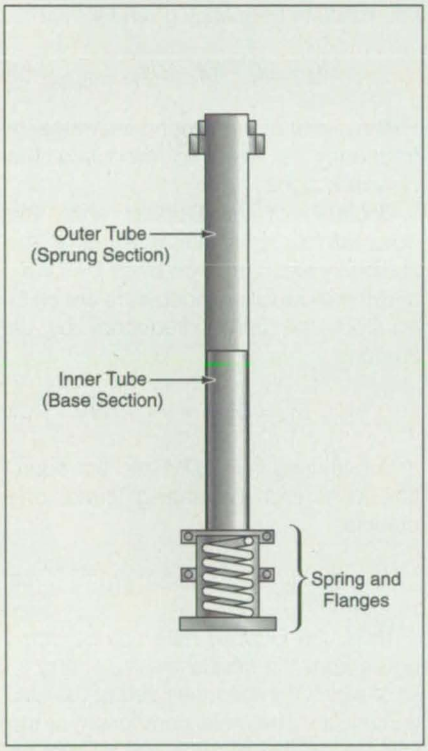
Extensible Circular Waveguide

Length can be changed without appreciable loss in radio-frequency performance.

NASA's Jet Propulsion Laboratory, Pasadena, California

In the antenna/waveguide assembly described in the preceding article, the third section is an extensible waveguide of circular cross section. This waveguide is required to function during several mission phases in which the spacecraft is experiencing significant dynamic displacements; it is designed to be capable of varying in length by as much as ±1/2 in. (±1.3 cm) without significant loss of radio-frequency performance and without loss of mechanical contact with mating waveguide sections at both of its ends.

The extensible waveguide (see figure) includes two telescoping thin-walled aluminum tubes plus a spring and flanges for axial preloading. One tube, denoted the "base section," has inner and outer diameters of 1.020 and 1.065 in. (25.91 and 27.05 mm), respectively. The other tube, denoted the "sprung section," has inner and outer diameters of 1.070 and 1.130 in. (27.18 and 28.70 mm), respectively along the lower part of its length, where it mates the with base section. Thus, the sprung section slides over the base section with a radial clearance of 0.0025 in. (0.064 mm).



The **Telescoping Inner and Outer Tubes** are spring-loaded toward extension to maintain contact with other waveguide sections (not shown) that mate with the ends.

The nominal lengthwise overlap between the tubes is about 6 in. (15 cm), and the overall length of the extensible waveguide is about 14 in. (36 cm). The mating surfaces in the overlap region are hard-anodized and impregnated with polytetrafluoroethylene for lubrication and to prevent contamination by wear particles; care was taken to restrict this surface treatment to the overlap region because hard-anodized aluminum performs poorly as a radio-frequency-conduit material.

The design of the extensible waveguide calls for the electromagnetic waves in question to propagate past the small inner diametral steps in the two tubes from 1.020 in. (25.91 mm) to 1.070 in. (27.05 mm), then back to 1.020 in. (25.91 mm). The transition to the final diameter is accomplished by incorporating, into the upper end of the sprung section, a 3-in. (7.62-cm)-long linear taper from an inner diameter of 1.070 in. (27.18 mm) to a final inner diameter of 1.020 in. (25.91 mm). In radio-frequency performance, overall changes in transmission-line mismatches associated with changes of length and stepped diameters were found to be tolerably small.

This work was done by Kevin Burke, Joseph Vacchione, and Tom Otoshi of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 9*** *on the TSP Request Card.*
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Electronic Systems

Two-Way, Noncoherent Precise Doppler Measurement System

Complexity, mass, input power, size, and cost of a spacecraft radio system could be reduced.

NASA's Jet Propulsion Laboratory, Pasadena, California

A proposed transceiver-based system for measuring Doppler shifts between a nominally stationary site and a moving object would be incoherent in the sense that signals returned by the transmitter from the moving objects would not be phase-locked to the uplink signal. The system was conceived for use in Earth-station and spacecraft communications systems for spacecraft navigation, and deep-space radio-science experiments, but the basic principle of the system is equally applicable to terrestrial Doppler measurements. Heretofore, radio systems in spacecraft have used coherent transponders for precise two-way Doppler measurement and have been coherent in that they have provided phase-locking of transmitted signals to the received signals. The main advantage of the proposed system is that the elimination of the requirement for coherence would make it possible to design a transceiver with reduced (relative to a coherent transponder) complexity, mass, input power, size, and cost.

The two-way noncoherent precise Doppler transceiver needs only one fixed-frequency oscillator to generate all transmitter and receiver frequencies. The need for controllable variable frequency oscillators and fixed frequency oscillators, and the switching systems used to select the appropriate oscillator, as used in the current coherent transponders, is eliminated. The use of one fixed frequency oscillator reduces the self-lock danger found in coherent transponder designs, thereby reducing the extensive analysis and isolation techniques currently needed to avoid the self-lock problems. The noncoherent transceiver approach shifts the complexity from the moving object to the nominally stationary site for measurement of precise two-way Doppler. A precise uplink signal is still required, and the downlink receiver must measure two signal frequencies instead of one.

The Doppler measurement is performed at the nominally stationary site (Earth station), and the transceiver is located in the nominally moving object (a spacecraft). The stationary site transmits an uplink signal at a carrier frequency f_1. At the moving object, the transceiver receives the uplink at a frequency Df_1, where D is the Doppler ratio. If for example, the moving object were traveling directly away from the stationary object at speed v, then the Doppler ratio is given by

$$D = [(c - v)/(c + v)]^{1/2} \qquad (1)$$

In the transceiver, a fixed-frequency reference oscillator runs freely at a frequency f_0. The output of this oscillator is fed to a multiplier to generate a downlink carrier signal at a frequency Mf_0, where M is a frequency-multiplication ratio. The received uplink signal at frequency Df_1 is mixed with the downlink carrier signal to produce a signal at a first intermediate frequency $Df_1 - Mf_0$. The signal at the first intermediate frequency is mixed with a multiple of the reference oscillator signal, Nf_0, to produce a signal at a second intermediate frequency given by

$$f_2 = Df_1 - (M + N)f_0 \qquad (2)$$

The signal at the second intermediate frequency is used to modulate the downlink signal.

Because of the Doppler shift, the downlink carrier signal received at the stationary site has a frequency $f_r = DMf_0$, and the modulation sidebands are shifted from the carrier frequency by an amount

$$f_s = Df_2 = D[Df_1 - (M + N)f_0] \qquad (3)$$

Substituting $f_0 = f_r/DM$ into the equation for f_s and rearranging terms, one obtains

$$D = \{[f_s + (1 + N/M)f_r]/f_1\}^{1/2} \qquad (4)$$

Thus, the Doppler ratio can be computed from the frequencies f_s, f_r, and f_1, all of which can be measured at the stationary site. The radial component of the velocity of the moving object can be derived from this Doppler ratio, using Equation (1).

This work was done by Robert C. Clauss, Martin I. Herman, James S. Border, Mark S. Ryne, Dimitrios Antsos, Leroy Tanida, and Daniel L. Rascoe of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information* ***write in 54*** *on the TSP Request Card.*
NPO-19922

Automated Apparatus Measures Radio Traffic

John F. Kennedy Space Center, Florida

An automated electronic apparatus measures radio traffic generated in 68 frequency channels by more than 2,000 mobile radio sets and associated radio subsystems at Kennedy Space Center. The data obtained by use of this system are to be used to design a new, spectrum-efficient, optimally sized radio-communication system. The apparatus includes two discone omnidirectional antennas at different locations, each antenna connected to its own receiver, which is capable of stepping through as many as 100 channels per second. Under control by a computer, each receiver scans all 68 channels during each second, generating a digital indication of the strength of the signal received in each channel. For each channel, the computer selects the stronger of the two signals, and if that signal is at least 10 dB

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above the noise floor, then the signal is regarded as a "good" signal and is counted toward the traffic statistics. The data thus collected during each day are processed to generate tables that show the traffic (in units of call-seconds), for each hour of the day. The data from the busiest hour of each day are then analyzed statistically by use of the Erlang B equation (a derivative of the Poisson equation for traffic engineering) to determine the number of radio frequencies needed for a trunking system to support the traffic.

This work was done by Richard B. Birr and David R. Wedekind of I-NET for **Kennedy Space Center**. *For further information,* ***write in 100*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Kennedy Space Center; (407) 867-2544. Refer to KSC-11854.

Self-Calibrating Signal-Conditioning Amplifier

Calibration is performed alternately on two signal-conditioning paths.

John F. Kennedy Space Center, Florida

An analog signal-conditioning amplifier for use with a transducer repeatedly calibrates itself using stable and accurate internal voltages. The purpose of the self-calibration scheme is to maintain accuracy of 15 bits (1 part in 32,768) of the analog and digital outputs of the amplifier and of the excitation voltage. The accuracy is maintained during the initial warmup, variations in temperature and humidity, and aging of components during normal operation.

The amplifier can be described more accurately as a system that comprises a pair of programmable-gain amplifiers, two multiplexers, an analog-to-digital converter, a digital signal processor, and two digital-to-analog converters configured to provide two nominally equivalent signal-conditioning paths (see figure). Various parts of the circuity in the two paths are made to alternate between calibration and normal signal-conditioning functions, and the frequency of alternation can be chosen conveniently low to allow adequate time for decay of all transient electrical responses to the calibration signals.

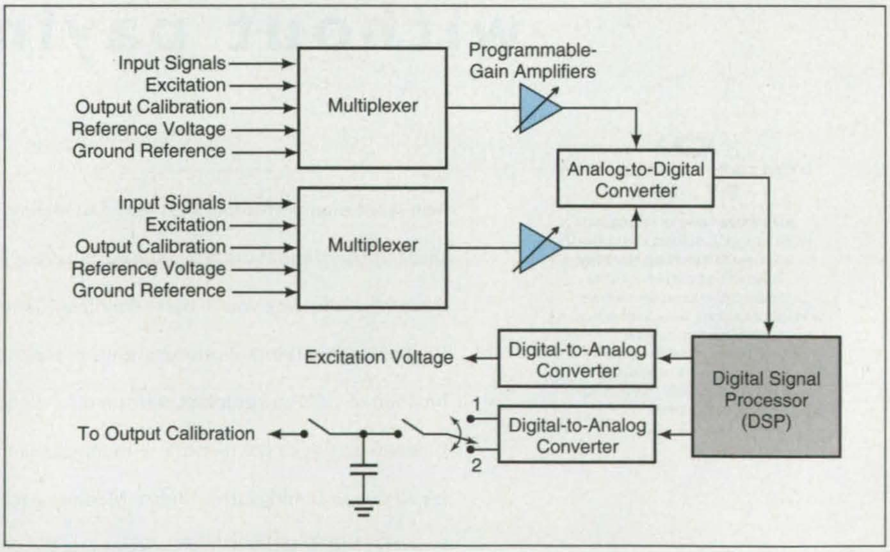
One important advantage of this scheme is that the frequency response of the amplifiers need not impose a limitation on the accuracy of calibration. Conversely, it is not necessary to make an engineering compromise between (1) a low-frequency-response amplifier (in which transients would not decay fast enough to allow accurate calibration with a high-frequency calibration waveform) and (2) a high-frequency-response amplifier (in which transients would settle rapidly enough but the noise level would be greater and could be great enough to degrade the accuracy of calibration).

The calibration signal in use at any given time can be one of the following: (1) a nonzero reference voltage for calibrating the input gain of the amplifier, (2) a zero reference voltage (ground reference) for removing any dc offsets, (3) an output reference voltage obtained from the output stage and used to calibrate the gain of the output stage, (4) an output zero reference obtained from the output stage and used to remove any voltage offset at the output stage, (5) a positive excitation voltage used to monitor the positive voltage applied to the transducer, (6) a negative excitation voltage used to monitor the negative voltage applied to the transducer. The use of a dual signal/calibration path allows for the accurate calibration of the amplifier while using a limited signal bandwidth.

The system operates as follows: The output from the transducer is connected to one of the input paths (called the "data path"), while the other path (called the "calibration path") is set to calibration mode. The circuits in the calibration path are sequentially excited with the various calibration voltages, allowing enough time for the response of the amplifier to settle to within 1 part in 65,536 of its final voltage. The digital signal processor samples data from each path separately. The digital signal processor uses the information obtained from the calibration path to calibrate the circuitry in that path; meanwhile, the transducer-output data are processed according to the normal signal-conditioning scheme in the data path.

Typically, the time needed to calibrate one path is less than one second. Once the circuits in the calibration path are fully calibrated, there is a transition to an interchange of the roles of the two paths: At first, both paths are configured as data paths. Then after waiting a short time for decay of transients, the former data path is configured as the calibration path. The process is then repeated so the calibration factors of both channels are repeatedly updated.

To maintain electrical isolation between the output and input stages, the output signal is transferred to the input calibration path by means of a capacitor that is switched in and out of the circuit. By using solid-state relays for this switching, an isolation greater than 10 GΩ at a potential of 2.5 kV can be obtained. The digital signal processor controls the solid-state relays to ensure that they are never turned on at the same time.



Two Programmable-Gain Amplifiers lie on two signal-conditioning paths, on which operation alternates between two modes; while one amplifier performs its normal signal-conditioning functions, the other one is calibrated.

This work was done by Pedro J.

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Medelius, Carl G. Hallberg, and Howard James Simpson of I-NET, Inc., for **Kennedy Space Center**. *For further information,* ***write in 99*** *on the TSP Request Card.*

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Training a Digital Neural Network

A modified back-propagation algorithm is used.

Lyndon B. Johnson Space Center, Houston, Texas

A method of training a digital neural network is based partly on the back-propagation method, which, heretofore, has been applicable to analog but not to digital neural networks. Figure 1 illustrates schematically a typical neural network and a typical use, in which the network is part of a feedback control system for a two-degree-of-freedom robotic manipulator. In this application, the neural network accepts the desired Cartesian coordinates (x, y) of the manipulator tip as input commands and responds by generating manipulator-joint-angle commands (θ_1, θ_2) to place the tip at the desired (x, y) .

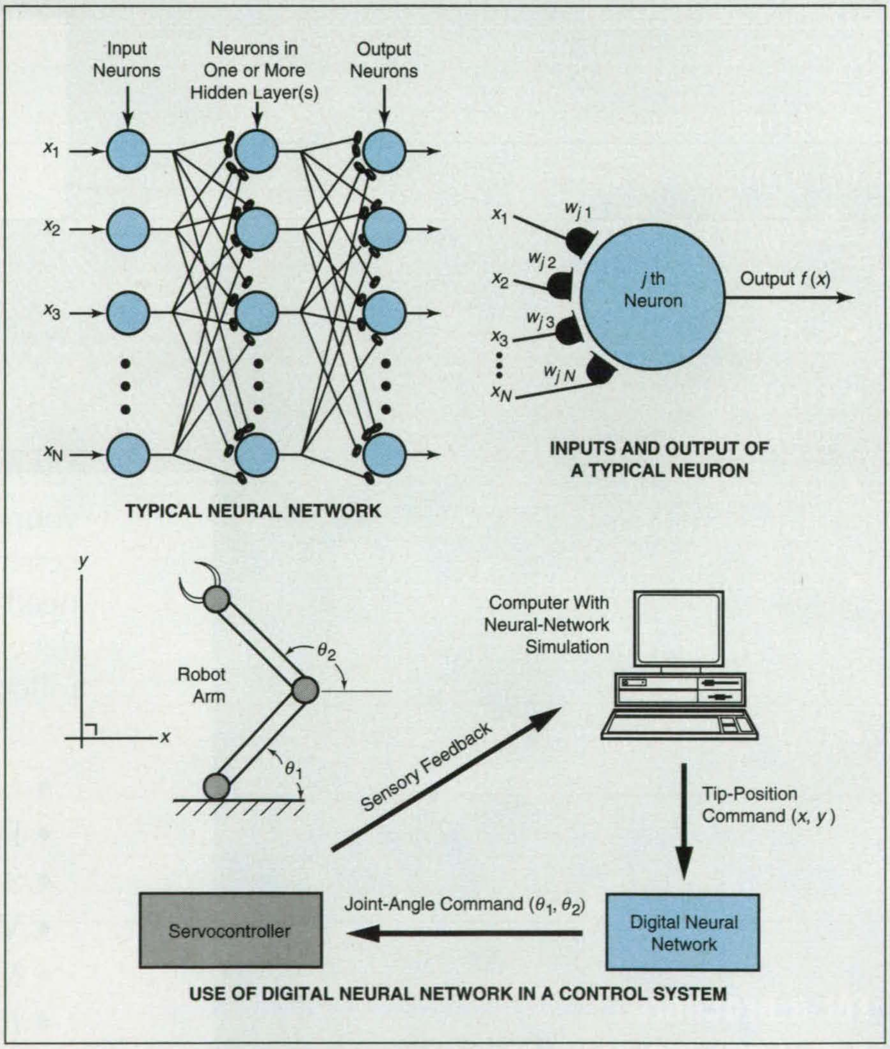
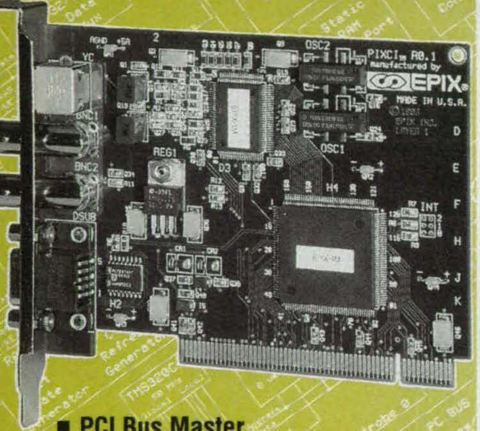


Figure 1. The **Neural Network Is Trained** to perform the transformation from (x, y) to (θ_1, θ_2). Training involves a modified version of the back-propagation method.

For this purpose, the neural network must be capable of operating in two modes: the performance mode described above, and the training mode, in which the neural network learns the transformation from (x, y) to (θ_1, θ_2). Training involves (a) the presentation, to the neural network, of a set of examples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of many different input/output pairs that span the range of (x, y) and corresponding exact (θ_1, θ_2) values and (b) the adjustment of the synaptic-connection weights in the network until the output errors — the differences between the actual (θ_1, θ_2) outputs and the exact (θ_1, θ_2) values for the given inputs — become acceptably small.

In the conventional back-propagation method, the errors are propagated back through the network from the output layer of neurons toward the input layer, and the weights are adjusted to minimize the errors. This process is repeated until some global measure of the errors becomes acceptably small. Typically, back-propagation learning is implemented by computer simulation.

The activation function of each neuron is a continuous, differentiable sigmoid function, which is typically of the form

$$f(x)=\frac{1}{1+e^{-x}}$$

where $f(x)$ is the output of the neuron and x is the weighted sum of inputs to the neuron. For the jth neuron in a given layer, the weighted sum of inputs is given by

$$x=\sum_i W_{ji}X_i$$

where W_{ji} is the synaptic-interconnection weight between this neuron and the ith neuron of the preceding layer and X_i is the output of that neuron. (If the jth neuron is in the input layer, then x equals simply the jth input, x_j. The conventional back-propagation method works as long as $f(x)$ is as described above; it does not work when $f(x)$ is a unit step function, as it is in a digital neural network. Accordingly, in the present method, the step function is initially approximated by a sigmoid function to enable back-propagation training.

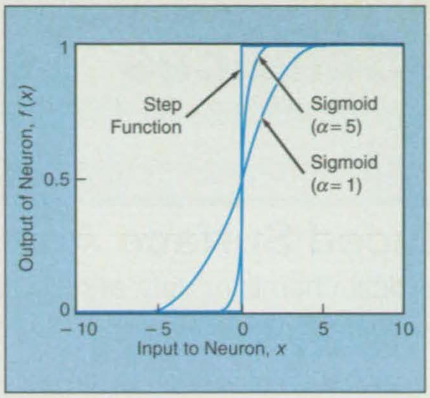

Figure 2. The **Tunable Actuation Function** approaches a step function as α increases.

In the present method, one begins with a computer simulation of an analog version of the neural network with a tunable activation function

$$\tilde{f}(x)=\frac{1}{1+e^{-\alpha x}}$$

where α is a positive value. Initially, α is set at 1 and the simulated neural network is trained by conventional back propagation. Next α is increased to make the sigmoid approximate a step function more closely (see figure 2). The back-propagation learning rate is adjusted accordingly, and the network is subjected to a further sequence of back-propagation iterations. This process is repeated until the output of every neuron in the hidden layer(s) is an acceptably close approximation of a binary output in that it lies either between 0 and ε or between $1 - \varepsilon$ and 1, where ε is a smaller number (typically, $\varepsilon = 0.01$). Once the desired close approximation has been achieved, the connection weights are converted to integers and downloaded into the digital neural network. This completes training, and the digital neural network can then execute the digital approximation of the input/output transformation in the performance mode.

This work was done by Steven E. Fredrickson and Larry C. H. Li of **Johnson Space Center**. *For further information,* ***write in 2*** *on the TSP Request Card.*

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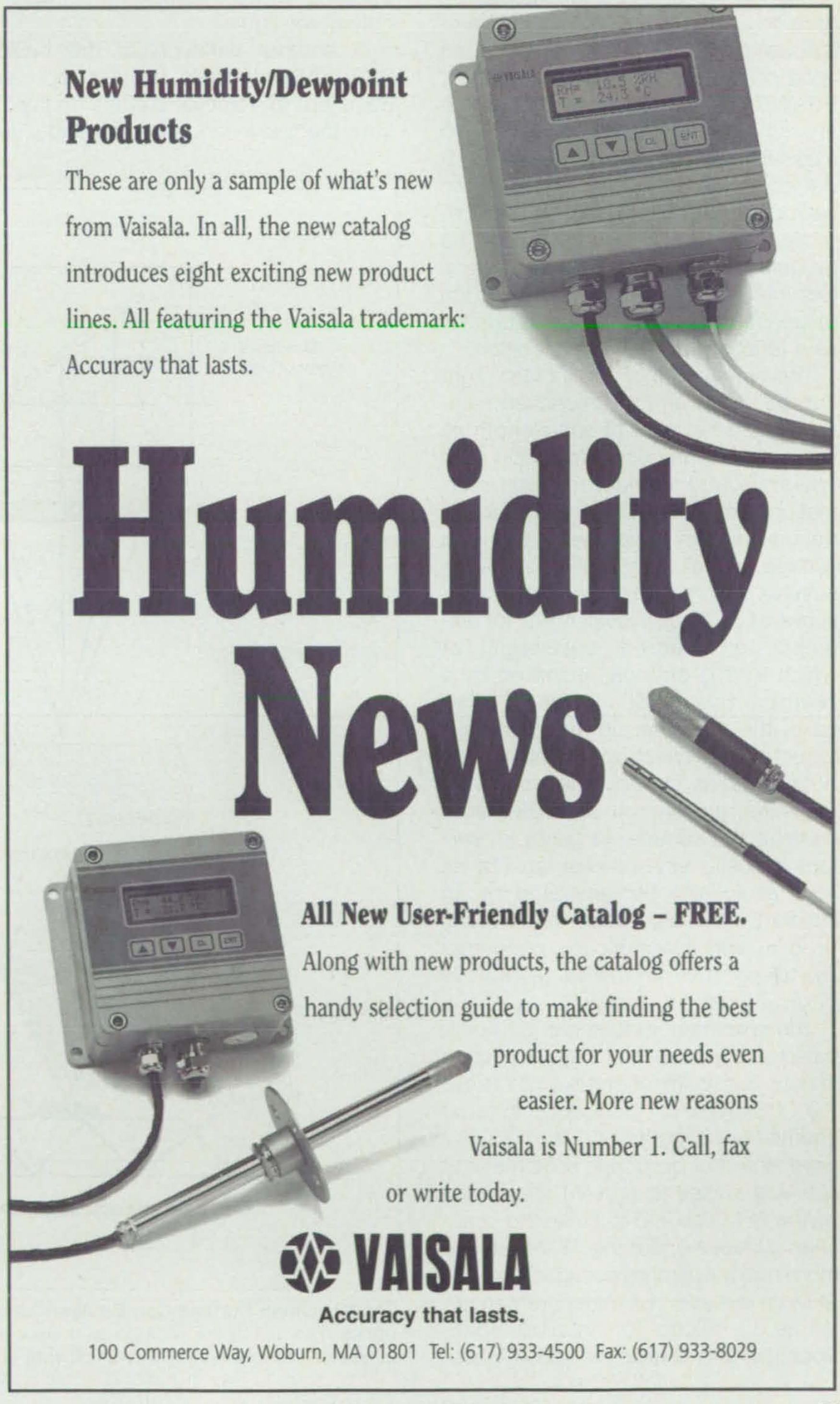
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Measuring Photoinduced Surface Acoustic Waves by AFM

This technique could provide analytical-chemistry data at high spatial resolution.

NASA's Jet Propulsion Laboratory, Pasadena, California

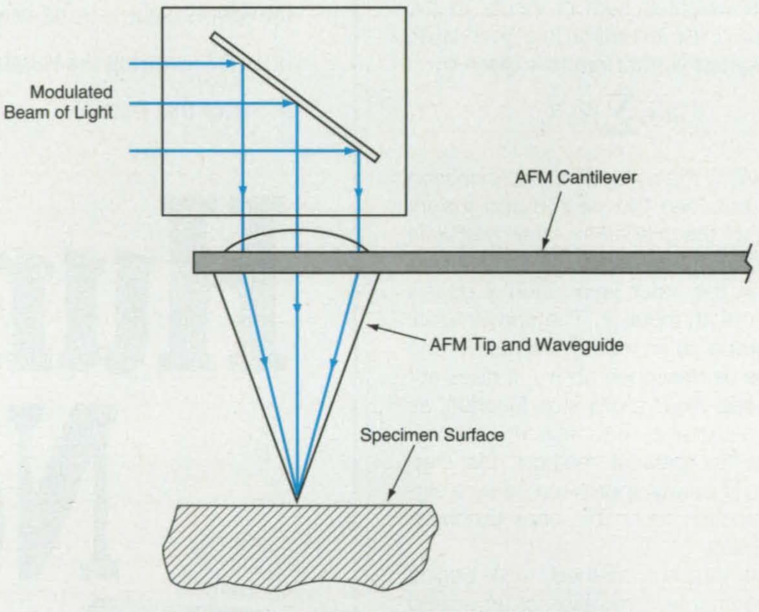
Photo-surface-acoustic-wave/atomic-force microscopy (PSAW/AFM) is an experimental technique that may prove useful in obtaining high-resolution data on spatial variations in the chemical compositions of surface layers on solid objects. As its name suggests, PSAW/AFM involves the use of an atomic-force microscope (AFM) to measure surface acoustic waves induced by incident light. The light can be monochromatic, quasi-monochromatic, or broadband and must be modulated at a suitable frequency. One measures the oscillations in the response of the AFM at that frequency as a function of AFM scan position.

The wavelength of the incident light can be varied and the response measured as a function of wavelength as well as of scan position to obtain both spectrally and spatially resolved information about the surface; that is, spectral information indicative of the local surface chemical composition. Alternatively, the response could be measured at a single wavelength; for example, an infrared wavelength at which light is strongly absorbed by a chemical species of interest. In either case, the AFM can be regarded as a detector in a spectrophotometer. The AFM acts as a local detector that measures the photothermal displacement at the surface. In principle, surface acoustic waves measurable by an AFM could also be generated by an incident modulated beam of electrons or ions, and spectroscopy performed by taking measurements at various particle kinetic energies.

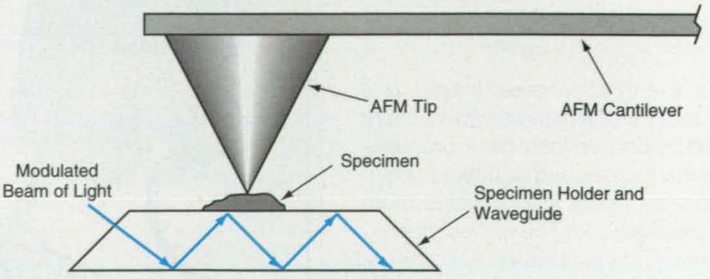
The specimen surface can be illuminated in any of several ways. In experiments that were undertaken to prove the PSAW/AFM concept, infrared beams (wavelengths of 1.9 to 20 μm) were aimed at polymeric specimens at glancing angles to prevent shadowing by the AFM tips and to strike the specimen surfaces under the AFM tips. In a more nearly optimum configuration, the AFM tip is made of a transparent material (e.g., silicon for infrared spectroscopy) and acts as an optical waveguide that concentrates the illumination onto a very small spot on the specimen surface (see figure). Another option is to use a sample holder as an optical waveguide.

In another variation of the basic PSAW/AFM concept, the AFM tip can be used to remove surface material from the specimen, and photoinduced acoustic deflections are measured with the illumination aimed at the tip after the tip has been disengaged from the specimen.

This work was done by Mark S. Anderson of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 7*** *on the TSP Request Card. NPO-19498*



ILLUMINATION USING AFM TIP AS A WAVEGUIDE



ILLUMINATION USING SPECIMEN HOLDER AS A WAVEGUIDE

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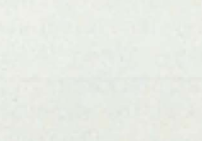

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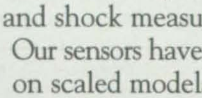

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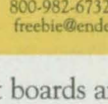

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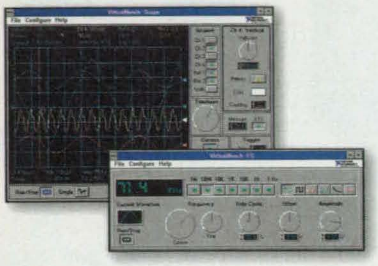

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For More Information Write In No. 413

High-T_c-Superconductor Bolometer With High Detectivity

The superconductive film is deposited on a thin sapphire substrate.

Goddard Space Flight Center, Greenbelt, Maryland

An improved transition-edge bolometer based on a superconductor with a high superconducting-transition temperature (high T_c) has been found to exhibit a detectivity of 6 × 109 cm·Hz$^{1/2}$/W at a frequency of about 4 Hz. As of the date of reporting, this was the highest detectivity observed in any high-T_c bolometer or, for that matter, of any thermal detector with cooling to a temperature no lower than that of liquid nitrogen.

Detectivity (usually abbreviated "D^*") is a figure of merit that summarizes the performance of a detector with respect to signal-to-noise ratio and frequency response. Detectivity is the reciprocal of an area-normalized noise equivalent power (NEP), which is a measure of the limit, imposed by noise, on the lowest detectable signal level.

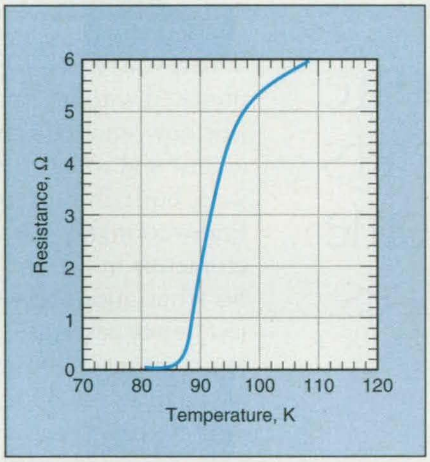

Figure 1. This **Resistance-vs.-Temperature Curve** shows the transition to and from superconductivity of the film of $YBa_2Cu_3O_{7-x}$ in the bolometer. For maximum D^*, the equilibrium temperature is set in the range of 90 to 91 K, where the curve is steepest.

In a transition-edge bolometer, the sensing element is a film of superconductive material mounted on a thin substrate maintained at an equilibrium temperature at or near T_c — preferably at a temperature in the range within which the rate of change of the electrical resistance (R) of the film with temperature (T) is greatest. In the case of the $YBa_2Cu_3O_{7-x}$ high-Tc superconductive film used in the present bolometer, this range was found to be 90 to 91 K (see Figure 1). The temperature is easily maintained at an equilibrium value in this range because it is above the boiling temperature (77 K) of liquid nitrogen at normal atmospheric pressure.

Using the four-wire-probe technique, a low bias current is applied to the film while the voltage drop caused by the current is measured to determine R. The bias current must be high enough to provide a voltage reading adequate for determining R as a function of T, but not so high that the heating caused by the current causes thermal runaway. When incoming thermal radiation (the radiation to be measured) strikes the substrate, it heats the substrate and film, causing T to rise above the equilibrium value

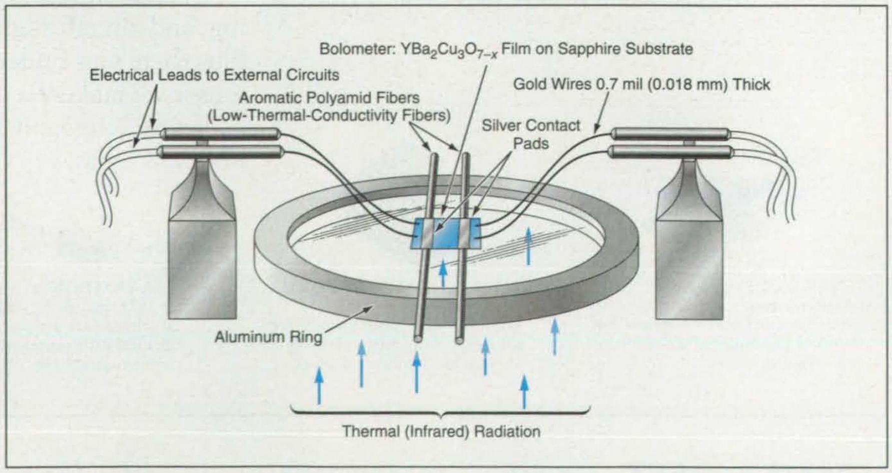

Figure 2. The **Bolometer Is Suspended** within the cooled vessel, near the window, by low-thermal-conductivity fibers.

and thus giving rise to a change in R. The change in R is thus a measure of the incident thermal radiation.

The bolometer is suspended in an evacuated vessel cooled to the equilibrium temperature near T_c. Thermal radiation is admitted through a window. Several design features help to maximize the D^* of this bolometer: To minimize the excess noise in the superconductive film, the film is deposited on a low-thermal-mass substrate; specifically, a substrate of sapphire (which has a low specific heat) only 25 μm thick. To maximize the absorption of thermal radiation, a layer of carbon black is deposited on the radiation-absorbing surface, which is the surface of the substrate opposite that of the superconductive film. To minimize thermal-conduction loss of signal, the substrate is suspended in the vessel by use of low-thermal-conduction aromatic polyamid fibers (see Figure 2).

Some proposed modifications in geometry are expected to lead to improved performance via fourfold reductions in heat capacity and thermal coupling. The D^* of a bolometer with these modifications would be about twice the D^* of the present bolometer.

This work was done by John C. Brasunas and Brook Lakew of **Goddard Space Flight Center**. *For further information,* ***write in 15*** *on the TSP Request Card. GSC-13667*

Dual-Element Tunneling Accelerometer With Dual Feedback

A low-frequency feedback loop keeps a proof mass at or near a nominal control position.

NASA's Jet Propulsion Laboratory, Pasadena, California

Figure 1 illustrates a dual-element, cantilever-spring-and-mass, quantum-mechanical-tunneling transducer designed to sense accelerations along one axis at frequencies from 5 Hz to 1 kHz. The larger of the two cantilever elements holds a proof mass, and the frequency of resonant vibration of this cantilever is less than 100 Hz; the smaller cantilever element has a resonance frequency somewhat above 2 kHz. Accelerations in the frequency range of interest cause the proof mass and its cantilever support to vibrate about a nominal quiescent point or control position. By use of the dual feedback circuit described below, the tip of the smaller cantilever is made to follow the movements of the proof mass, and the desired measurement of acceleration is extracted from the feedback signal used to control the smaller cantilever.

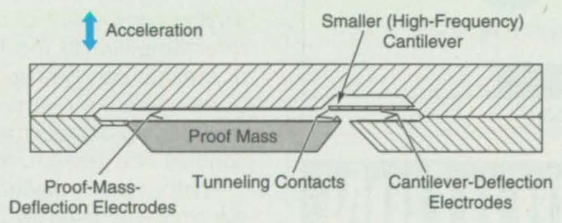

Figure 1. In this **Dual-Element Tunneling Accelerometer**, the smaller cantilever is electrostatically deflected to make it follow the motion of the proof mass on the larger cantilever. The larger cantilever is electrostatically deflected to make slow adjustments in its quiescent operating point.

Like other quantum-mechanical-tunneling transducers, this one operates according to a feedback control scheme in which a fixed bias voltage is applied across a small gap (about 10 Å wide) between two tunneling contacts. In this case, one of these contacts is on the proof mass, while the other is on the smaller cantilever. The bias voltage gives rise to a quantum-mechanical-tunneling current of electrons between the elec-

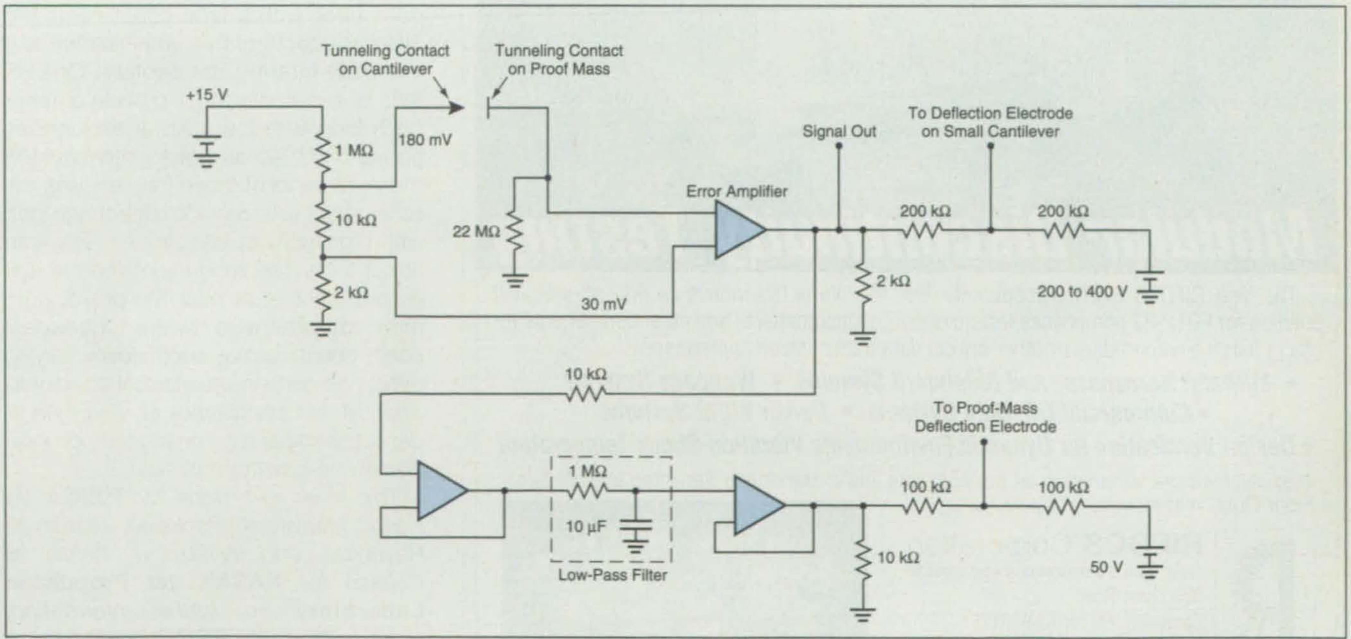

Figure 2. This **Dual Feedback Circuit** generates the deflection and readout voltages for the accelerometer illustrated in Figure 1.

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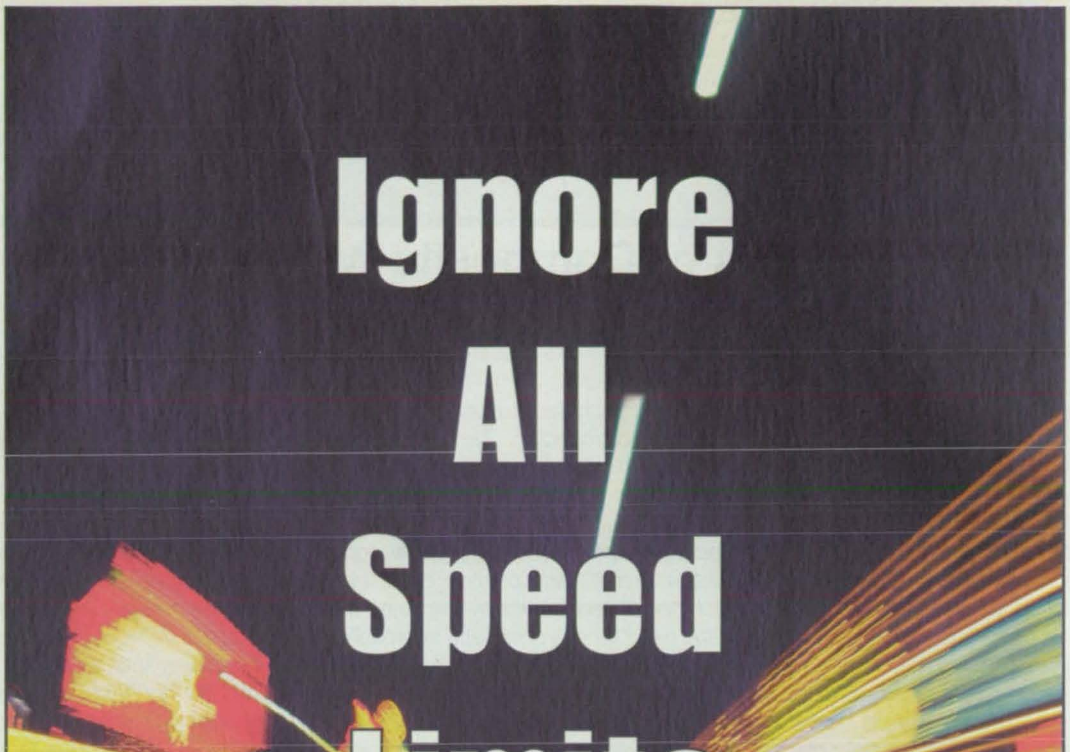
trodes, and the magnitude of this current depends on the size of the gap. The deflection of the smaller cantilever is controlled by applying a voltage to a pair of electrostatic deflection electrodes; this voltage is adjusted according to the feedback control scheme to maintain a constant tunneling current and thus a constant gap, thereby causing the smaller cantilever to follow the proof mass.

Figure 2 illustrates the dual feedback control circuit, which includes two feedback control loops; one that covers all frequencies from zero up through the measurement frequency range of interest, and one for lower frequencies only. In the all-frequency loop, an error amplifier compares the tunneling current with a reference value that corresponds to the prescribed constant gap width. The output of the error amplifier is added to an offset voltage to obtain the deflection voltage described above; this voltage is applied to the deflection electrodes for the smaller cantilever. The error amplifier provides the feedback loop with high gain for control of the small cantilever, which maintains the tunneling current at or near the desired value. The time-varying component of the output of the error amplifier in the frequency range of interest can be used as the readout signal because it is proportional to the time-varying displacement and acceleration that one seeks to measure.

Another pair of electrostatic deflection electrodes is used to adjust the quiescent point of the larger cantilever and proof mass. The deflection voltage applied to these electrodes is generated similarly to the other deflection voltage, except that the output of the error amplifier is processed through a low-pass filter with a time constant of 1 s. The net effects of this amplification and low-pass filtering are twofold: One effect is a null effect; to provide a feedback loop with low gain at frequencies above 5 Hz (so as not to interfere with measurements at those frequencies); the other effect is to provide a feedback loop with high gain at frequencies less than about 1 Hz. This loop maintains the quiescent point at or near the preset optimum or otherwise desired quiescent point, counteracting such slowly varying effects as drifts in mechanical characteristics of the cantilevers or changes in deflection caused by changes in orientation in the gravitational field.

This work was done by Thomas W. Kenny, Howard K. Rockstad, Joseph K. Reynolds, and William J. Kaiser of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 98*** *on the TSP Request Card.*
NPO-19259



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Materials

Probabilistic Analysis of Composite-Material Structures

Uncertainties at the constituent, ply, laminate, and whole-structure levels are taken into account.

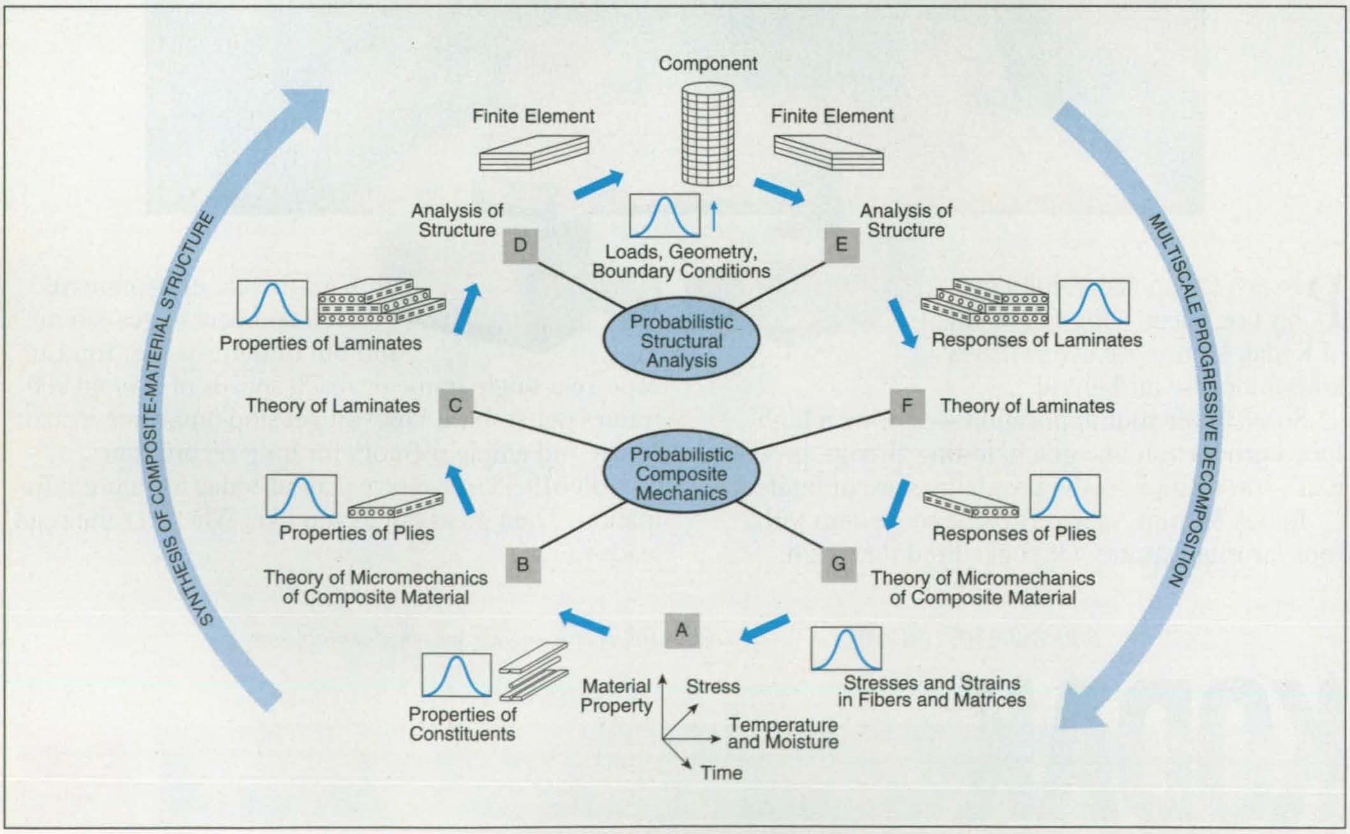
Lewis Research Center, Cleveland, Ohio

A probabilistic method for analysis of structures made of laminated composite (matrix/fiber) materials has evolved during recent years. This method provides for computation of the mechanical properties of structures at levels from microscopic to macroscopic and for predicting fatigue lives under various hygrothermomechanical loading conditions. The method is implemented in the Integrated Probabilistic Assessment of Composite Structures (IPACS) computer code, which performs complete probabilistic analyses of composite-material structures, taking account of uncertainties in sizes and shapes, boundary conditions, properties of materials, laminate layups, and loads.

The properties of composite materials depend on a number of primitive variables; these include properties of the fiber and matrix materials at the constituent level, plus such fabrication variables as the fiber volume ratio, the void volume ratio, the ply orientation, and the ply thickness at the ply level. Because these primitive variables are statistical in nature, the mechanical properties of a typical composite-material item cannot be reliably quantified deterministically; this gives rise to the need for a probabilistic approach.

The basic probabilistic approach embodied in the present method begins with the identification of uncertain variables at every structural level such as at the constituent, ply, or laminate level. The uncertain variables are then filtered through an analyzer, which combines composite mechanics, structural mechanics, and probability theory. The output of the analyzer is the desired set of structural responses and/or properties; for example, displacement, stress, strain, buckling load, natural frequency of vibration, and/or fatigue life.

The probabilistic calculation of such responses and properties can be performed by the Monte Carlo simulation method, but this method tends to be too computationally expensive in composite-material applications. To save computation time, the present method, as implemented in IPACS, integrates composite mechanics, finite-element computational methods, and fast-probability-integration algorithms. Fast probability integration (FPI) is an approximate technique for the probabilistic analysis of the performance of a structure. The major advantage of FPI is its computational speed, which exceeds that of the Monte Carlo method by a factor of the order of 10 or even more. Thus constituted, IPACS provides efficient and affordable means for the probabilistic assessment of composite structures (see figure) with inherent



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uncertainties and operating in uncertain environments.

IPACS integrates several NASA computer programs developed in recent years, including COBSTRAN, PICAN, and NESSUS. COBSTRAN (Composite Blade Structural Analyzer) is a dedicated finite-element-model generator for use in analyzing composite-material structures. PICAN (Probabilistic Integrated Composite Analyzer) enables the computation of the perturbed and probabilistic composite-material properties at the ply and the laminate levels. NESSUS (Numerical Evaluation of Stochastic Structures Under Stress) determines the perturbed and probabilistic structural responses at global, laminate, and ply levels. PICAN and NESSUS share the FPI (Fast Probability Integrator) software module for application of FPI algorithms to obtain cumulative distribution functions of the properties of materials and the responses of structures.

In IPACS, the uncertain primitive variables at constituent and ply levels are selectively perturbed several times in order to create a data base for the determination of the relationship between the desired structural response (or the desired material property) and the primitive variables. For every given perturbed primitive variable, micromechanics is applied to determine the corresponding perturbed mechanical properties at the ply and laminate levels. Laminate theory is then used to determine the perturbed resultant relationships among forces, strains, moments, and curvatures. With these relationships at the laminate level, a finite-element perturbation analysis is performed to determine the perturbed structural responses that correspond to the selectively perturbed primitive variables. This process is repeated until enough data are generated and the proper relationships among structural responses and primitive variables can be determined through a numerical procedure.

With the foregoing relationships plus the probabilistic distributions of the primitive variables in hand, FPI is applied. For every discrete response value, a corresponding cumulative probability can be computed quickly by FPI. This process is repeated until the cumulative distribution function (CDF) can be appropriately represented. The probabilistic material properties at ply and laminate levels are also computed in the same way as for the structural responses. The output information from FPI for a given structural response includes its discrete CDF values, the coefficients for a special type of probability distribution function, and the factors of sensitivity of the response of the structure to the primitive variables.

In using IPACS to determine the fatigue life of a structure, one first identifies the most critical areas of the components of the structure on the basis of finite-element analysis. The force and the moment resultants at the critical sections are saved for the computation of the fatigue life by use of a durability-analysis module in PICAN. The cyclic life is determined on the basis of the first-ply-failure criterion. According to this criterion, the number of cycles of any given set of loading combinations that give rise to failure in one of the plies at the critical section is assumed to give a conservative estimate of the cycle life of a laminate. (The laminate, by virtue of the remaining intact plies, may be able to survive additional cycles of load.)

This work was done by Pappu L. N. Murthy and Christos C. Chamis of **Lewis Research Center**, *Michael C. Shiao of Sverdrup Technology, Inc., and Leslie D. G. Liaw of Ford Motor Corp. For further information,* ***write in 44*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commerical Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7-3, 21000 Brookpark Rd., Cleveland, OH 44135. Refer to LEW-16092.

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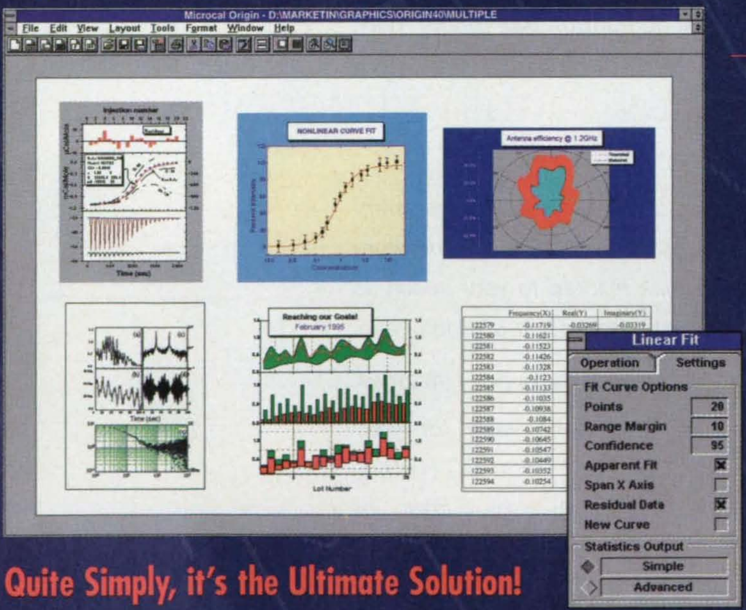

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Physical Sciences

Program Computes Radiative Transfers of Heat

The Thermal Radiation Analyzer System (TRASYS) is a computer program that provides a generalized capability for solving the radiation-related aspects of thermal-analysis problems. TRASYS computes the total thermal-radiation environment for a spacecraft in orbit. It calculates data on radiative interchanges of heat among nodes of the spacecraft as well as data on rates of incidence and absorption of heat from environmental radiant sources. TRASYS provides data of both types in a format directly usable by such thermal-analyzer programs as SINDA/FLUINT (available from COSMIC, program number MSC-21528).

One primary feature of TRASYS is that it enables users to write their own driver programs to organize and direct preprocessor and processor library routines in solving specific thermal-radiation problems. A preprocessor routine first reads and converts the user's geometric input data into the form used by the processor library routines. Then a preprocessor routine accepts the user's driving logic, written in the TRASYS-modified FORTRAN language. In many cases, the user has a choice of routines to solve given problems. Users can also provide their own routines where desirable. In particular, the user can write output routines to provide for an interface between TRASYS and any thermal-analyzer program that is based on an analogy to a network of resistors and capacitors.

Input to TRASYS consists of options and edit data, model data, and logic-flow and operations data. Options and edit data provide for basic program control and capability for editing by the user. The model data describe the problem in terms of geometric and other properties. This information includes data on surface geometry, documentation, nodes, block coordinate systems, form factors, and fluxes. Logic-flow and operations data convey the user's driver logic, including the sequence of subroutine calls and the subroutine library. Output from TRASYS consists of the internode-radiation data and the incident-and-absorbed-heat-rate data mentioned above. The flexible structure of TRASYS allows considerable freedom in the definition and choice of method of solution of a thermal-radiation problem. The flexibility has also made it possible for TRASYS to retain the same basic input structure as the authors update other parts of the software to keep up with changing requirements.

The following are among the important features of TRASYS:

- Capability for solving problems with sizes up to 4,000 nodes (3,200 in the VAX/VMS version, which is one of three versions, as described below) with shadowing by intervening opaque or semitransparent surfaces;
- Choice of diffuse, specular, or diffuse/specular radiant-interchange solutions;
- A restart capability that minimizes recomputation;
- Macroinstructions that automatically provide the executive logic for generating orbits, which logic optimizes the use of previously completed computations;
- A time-variable-geometry software package that provides automatic pointing of the various parts of an articulated spacecraft and an automatic look-back feature that eliminates redundant form-factor calculations;
- Capability to specify names of submodels to identify sets of surfaces or components as an entity; and
- Subroutines to perform functions that save and recall the internodal and/or space form factors in subsequent steps for nodes with fixed geometry during a variable-geometry run.

There are three machine versions of TRASYS v27: a DEC VAX version, a Cray UNICOS version, and an HP9000-series 700/800 version. All three versions require the installation of the NASA Device Independent Graphics Library, v5.7 (NASADIG 5.7), which is available from COSMIC bundled with TRASYS. NASADIG 5.7 is a plotting-software package that provides a pictorial representation of input geometry, orbital and orientational parameters, and heating-rate output as a function of time. NASADIG 5.7 supports Tektronix terminals. Please note that TRASYS v27 is not compatible with NASADIG 6.0.

The CRAY version of TRASYS v27 is written in FORTRAN 77 for batch or interactive execution and has been implemented on CRAY X-MP- and CRAY Y-MP-series computers running UNICOS. The standard medium for distribution of the CRAY version without NASADIG 5.7 (MSC-21959) is a 1,600-bit/in. (630-bit/cm), 9-track magnetic tape in UNIX tar format. The standard medium for distribution of the CRAY version with NASADIG 5.7 (COS-10040) is a set of two 6,250-bit/in. (2,461-bit/cm), 9-track magnetic tapes in UNIX tar format. Alternate distribution media and formats are available upon request.

The DEC VAX version of TRASYS v27 is written in FORTRAN 77 for batch execution (only the plotting driver program is interactive) and has been implemented on a DEC VAX 8650 computer under VMS. Since the source codes for MSC-21030 and COS-10026 are in VAX/VMS text library files and DEC Command Language files, COSMIC will provide the following versions of the program in the noted formats only: The DEC VAX ver-

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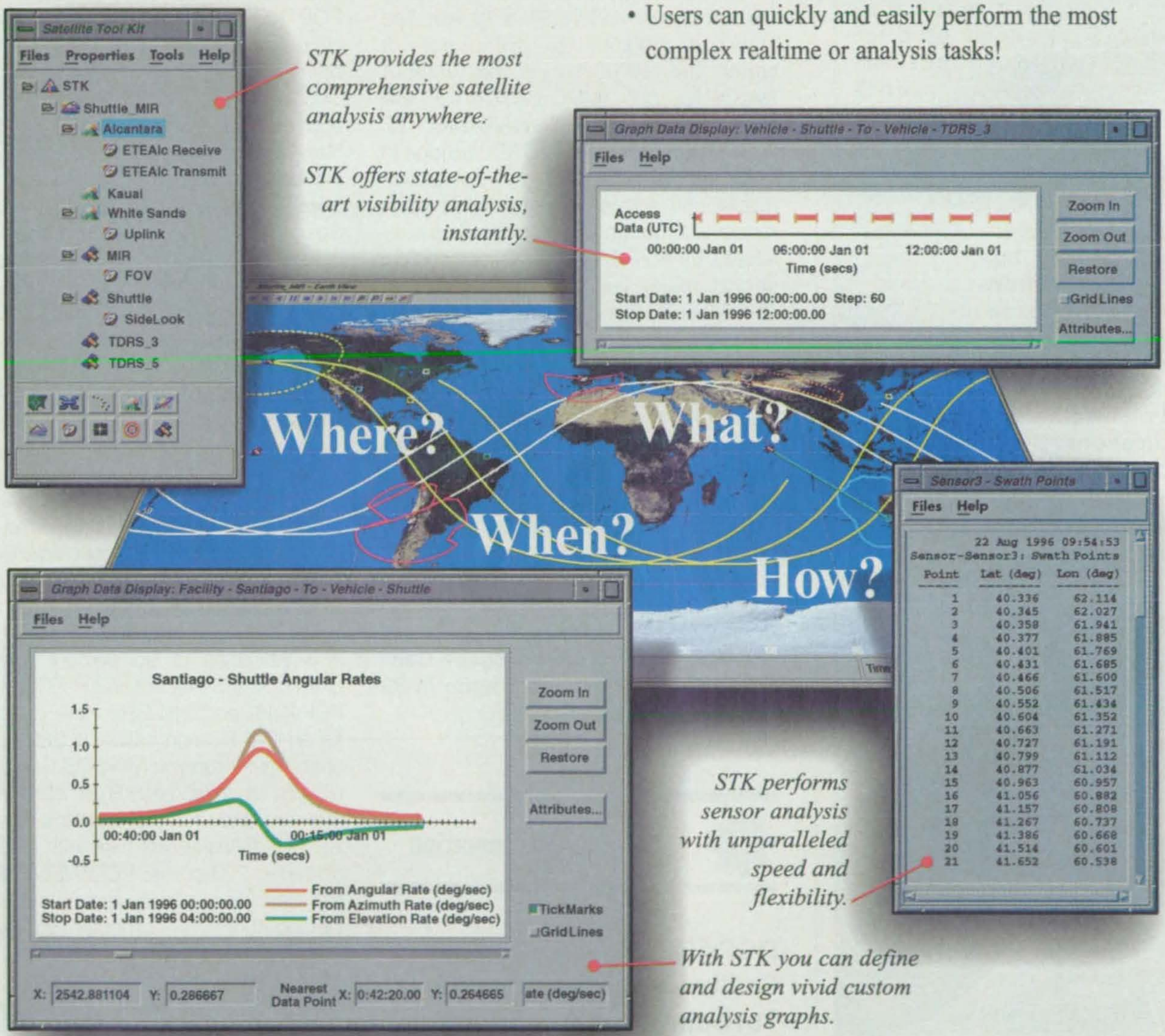

Start Date: 1 Jan 1996 00:00:00.00 Step: 60
Stop Date: 1 Jan 1996 12:00:00.00

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Stop Date: 1 Jan 1996 04:00:00.00

X: 2542.881104 Y: 0.286667 Nearest Data Point X: 0:42:20.00 Y: 0.264665 ate (deg/sec)

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            22 Aug 1996 09:54:53
 Sensor-Sensor3: Swath Points
  Point    Lat (deg)   Lon (deg)
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      1       40.336      62.114
      2       40.345      62.027
      3       40.358      61.941
      4       40.377      61.885
      5       40.401      61.769
      6       40.431      61.685
      7       40.466      61.600
      8       40.506      61.517
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sion of TRASYS without NASADIG 5.7 (MSC-21030) is available on a 1,600-bit/in. (630-bit/cm), 9-track magnetic tape in VAX BACKUP format (standard distribution medium) or in VAX BACKUP format on a TK50 tape cartridge; the DEC VAX version of TRASYS with NASADIG 5.7 (COS-10026) is available in VAX BACKUP format on a set of three 6,250-bit/in. (2,461-bit/cm), 9-track magnetic tapes (standard distribution medium) or a set of three TK50 tape cartridges in VAX BACKUP format.

The HP9000 version of TRASYS is written in FORTRAN 77 for implementation on HP9000 series 700/800 computers running HP-UX v8.07 or higher. The standard medium for distribution of either the HP9000 version without NASADIG 5.7 (MSC-22379) or the HP9000 version with NASADIG 5.7 (COS-10053) is a 4-mm DAT cartridge in UNIX tar format. Alternate distribution media and formats are available upon request. Although the modifications necessary to port TRASYS v27 to HP-UX should make this machine version of TRASYS v27 the easiest version to port to other UNIX-type computers, one would still have to make a number of nontrivial modifications to do so. Those interested in porting TRASYS v27 to other UNIX-type computers should keep in mind that, unfortunately, neither the author of the program nor COSMIC will be able to provide support or assistance for porting efforts. TRASYS was last updated in 1993.

This program was written by Gordon E. Anderson of Lockheed Engineering & Sciences Co. for **Johnson Space Center**. *For further information,* ***write in 89*** *on the TSP Request Card.*
MSC-22379

Machinery/Automation

PCPANEL/PNLGRF: Software for Computing Turbomachinery Flows

The PCPANEL program uses an integral-equation solution (panel) method to solve two-dimensional fluid flow problems on a personal computer. The solution method solves approximate governing equations of motions for blade-to-blade, steady-state flow problems in turbomachinery and has been used for several years in the design of turbomachinery blades. PNLGRF is an interactive graphical-interface program written specifically to enable visual analysis of the flow solutions generated by PCPANEL. It gives engineers a very rapid means of assessing the aerodynamic potential of a design. The combination of PCPANEL and PNLGRF provides designers with a powerful, yet cost-effective software tool. The run time for the flow solver is measured in minutes on personal computers of modest power. As a result, the amount of person-hours needed to design and analyze aerodynamic shapes is minimized.

The working fluid is assumed to be inviscid, irrotational, and a perfect gas. The integral equation solution used by PCPANEL calculates the flow around single or multi-element blade shapes that lie on a surface of revolution. It also can calculate flows through planar cascades and around isolated airfoils. PCPANEL has been demonstrated to yield good results for subsonic flows of mach numbers ≤0.5 around isolated airfoils. Solutions for transonic turbomachinery blade-to-blade flows can be obtained, but accuracy decreases with increasing mach number. Turbomachinery solutions are the most accurate for flows with mach numbers < 0.9.

The output of PCPANEL includes the effects of compressibility, radius change, blade-row rotation, and variable stream sheet thickness. The compressible-flow output is the most useful to the user. The output includes a summary of the solution, the integrated force coefficients, and details of the flow on the body surface.

PCPANEL is written in Microsoft FORTRAN 5.0, and PNLGRF is written in a combination of 95 percent Microsoft QuickC and 5 percent MS FORTRAN 5.0. PCPANEL and PNLGRF were developed for an IBM PC-compatible 80386 or higher computer running MS-DOS 3.3 or higher with at least 512KB of conventional memory and, for the graphics code, at least a CGA graphics card with resolution of 640 × 200 pixels. PCPANEL/PNLGRF has been successfully implemented on a DECpc 486DX/33 computer running MS-DOS 5.0 and an IBM PC 486DX/33 computer running Windows 95. Sample executable codes are provided. The standard distribution medium for PCPANEL/PNLGRF is one 3.5-in. (8.89-cm), 1.44MB, MS-DOS-format diskette. The contents of the diskette have been compressed by use of the PKWARE archiving software tools. The utility software to unarchive the files, PKUNZIP.EXE v2.04g, is included. PCPANEL/PNLGRF was released in 1996.

This program was written by Eric R. McFarland of **Lewis Research Center**. *For further information,* ***write in 77*** *on the TSP Request Card.*
LEW-16325

Industry Focus: Mechanical Tech Briefs

Analyzing Vibrations To Detect Damage on Gear Teeth

A statistical parameter gives early indication of gear tooth damage.

Lewis Research Center, Cleveland, Ohio

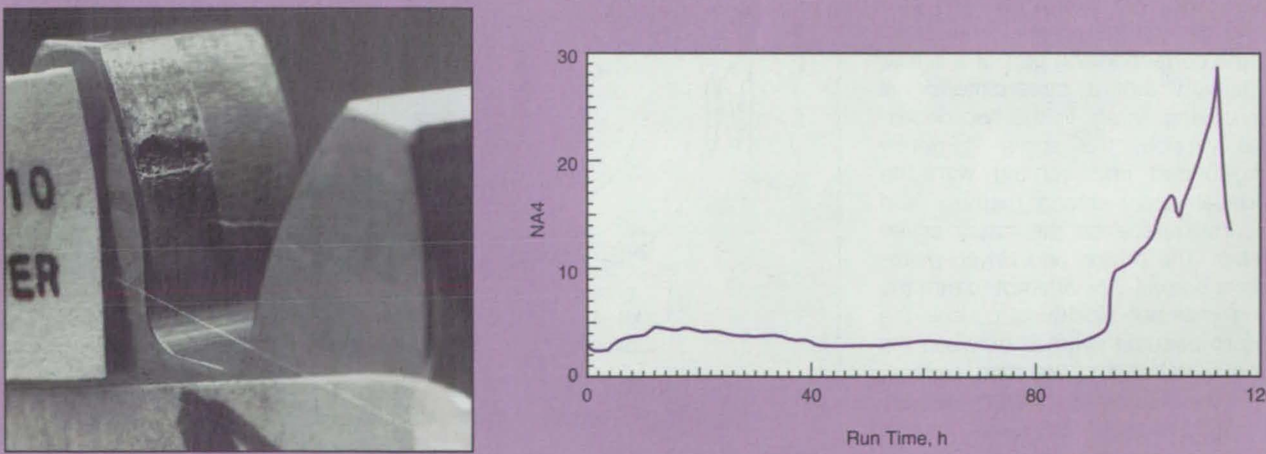
"NA4" represents a statistical parameter that is computed from measurements of vibrations in gear trains to detect damaged gear teeth. NA4 provides an indication that is sensitive to the major types of gear-damage modes, which include gear-tooth fatigue cracks, surface pitting, and heavy wear and scoring. NA4 and other techniques are being developed to provide timely warnings of the need for maintenance, or for quick action to prevent further damage. NA4 was primarily intended to enhance current vibration-monitoring systems in helicopters, where about 32 percent of serious rotorcraft accidents were found to be attributed to defects in the engines and transmissions. NA4 can be applied to other geared systems where advance warning of gear damage would prove to be beneficial.

Vibrations in a gear train are measured using an accelerometer mounted on the gear-train housing. It is also necessary to obtain a synchronizing pulse to correlate the vibration with the rotation of the gear being monitored. The analog vibration data is converted to digital form and time averaged using the synchronizing pulse in order to eliminate noise and vibration incoherent with the period of revolution of the gear being analyzed. This digitized, time-averaged signal is used as the input for the NA4 method.

Constructing a residual signal from the digitized, time-averaged vibration signal is the first step in the NA4 method. The residual signal is obtained by removing the regular meshing components (shaft frequency and harmonics, along with the primary meshing frequency and harmonics of the gear) from the digitized, time-averaged signal. This eliminates the normal vibration pattern of the gear which dominates the gear vibration signal.

NA4 then uses a number of statistical techniques to detect the various gear damage modes. NA4 is calculated by taking the kurtosis (fourth statistical moment) of the residual signal and dividing this by the square of the current run-time averaged variance of the residual signal. The kurtosis is used to amplify any impulsive elements in the residual signal resulting from a fatigue crack or heavy pitting on one or two teeth. Dividing the kurtosis by the time-averaged variance of the residual signal normalizes the NA4 parameter. This operation also helps NA4 to react to those damage modes which increase the overall signal level, such as heavy wear and scoring, or distributed pitting damage. The way this works is the changes in the residual signal are constantly being compared to a weighted baseline for the gear in "good" condition. An overall increase in the residual signal results in an increase in NA4. This allows NA4 to grow with the severity of the fault until the average of the variance itself changes. Because it is normalized, NA4 is dimensionless, with a value of 3, under nominl conditions.

NA4 was applied to a variety of gear fatigue runs where the damage ranged from minor surface pitting over a number of teeth to gear tooth fatigue cracks which resulted in complete tooth fracture. NA4 was able to indicate the onset of damage, and, in most cases, continue to indicate damage as the damage spread and increased in severity. An example test is shown in the figure. Spur gears with 28 teeth each and a pitch diameter of 88.9 mm were loaded to a torque of 74.6 N·m and rotated at a speed of 10,000 r/min on a gear fatigue test machine. At approximately 94 hours



NA4 Indicates the Onset of Pitting as its value increases from the nominal value of 3 to a value of 9.6 at approximately 96 hours into the test. NA4 continues to increase as the pitting damage progresses.

into the test, NA4 jumped from its nominal value to a value of 9.6, indicating the start of tooth surface pitting. NA4 continued to increase as the pitting damage increased and spread to more teeth. NA4 has also been successfully tested on spiral bevel gears and face gears.

This work was done by James J. Zakrajsek and Dennis P. Townsend of **Lewis Research Center** *and Harry J. Decker, Robert F. Handschuh, and David G. Lewicki of the U.S. Army Research Laboratory. For further information,* ***write in 62*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7–3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-15974.

Three-Dimensional Roller Locking Sprags

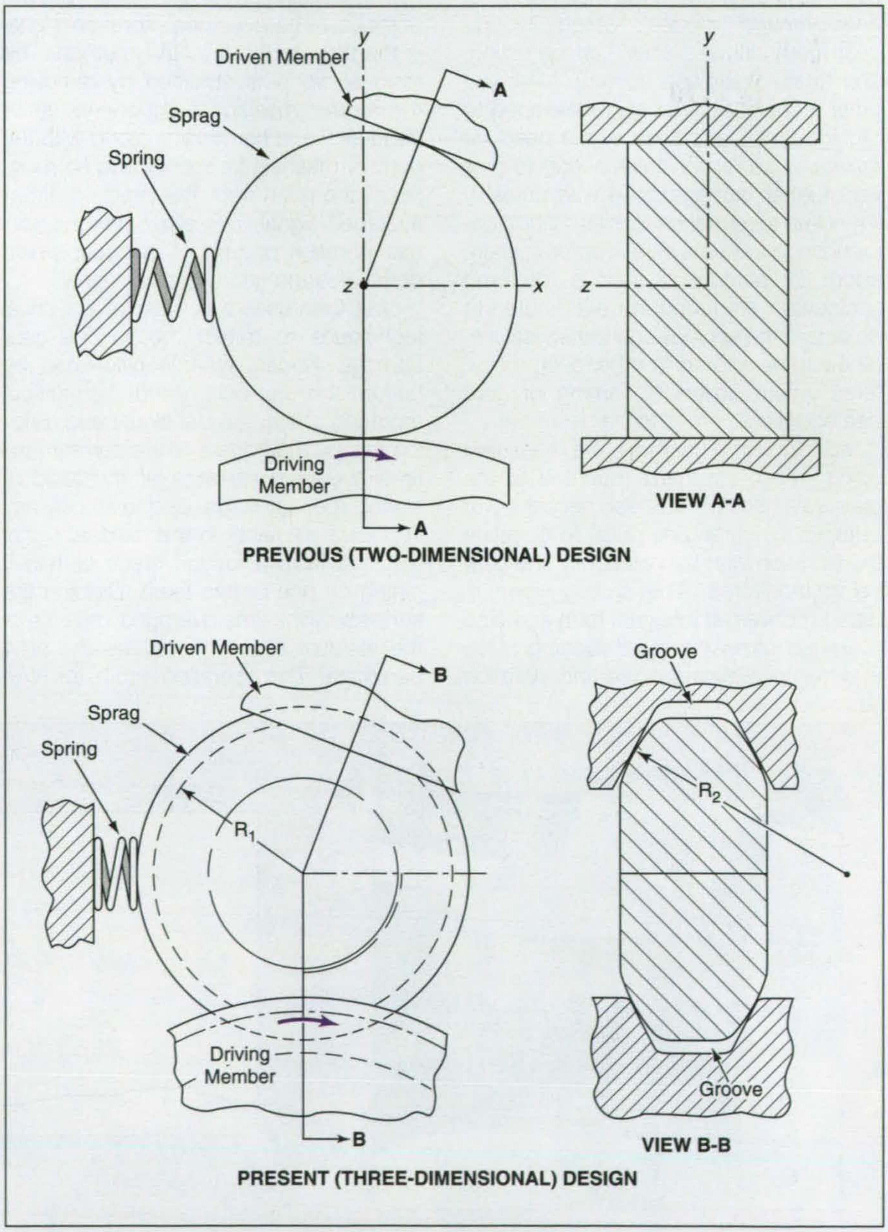
Advantages include increased locking effectiveness and decreased contact stresses.

Goddard Space Flight Center, Greenbelt, Maryland

Improved roller locking sprags that feature contact surfaces with three-dimensional (convex and/or concave toroidal) shapes have been invented for use in roller brake and clutch mechanisms. Older sprags designed for the same purposes have two-dimensional (cylindrical) shapes. As described below, the three-dimensional locking sprags offer several advantages over the two-dimensional sprags. [Three-dimensional roller locking sprags with more complex designs, plus mechanisms that contain them, were described in two prior *NASA Tech Briefs* articles, though not in explicit comparison with two-dimensional roller locking sprags. Those articles were "Clutch Combined With Screw-Released Roller Brake" (GSC-13674), Vol. 20, No. 12 (December 1996), page 94; and "Roller Unlocking Sprags" (GSC-13692), Vol. 20, No. 12 (December 1996), page 96.]

Within the basic two- and three-dimensional schemes, the sprags and mating parts can be designed in a large variety of sizes and shapes. To illustrate the basic principles and the differences between the two schemes, the figure shows part of a one-way roller clutch or brake mechanism with a relatively simple two-dimensional roller locking sprag, plus the corresponding part of a similar mechanism with a three-dimensional roller locking sprag. In the two-dimensional version, the sprag is gently spring-loaded into contact with the cylindrical rotary driving member and the cam surface on the rotary driven member. The driving and driven members are coaxial. Any attempt to turn the driving member clockwise causes the sprag to become jammed between the driving member and the cam surface. The frictional force associated with this jamming transmits clockwise torque from the driving to the driven member. Any attempt to turn the driving member counterclockwise causes the sprag to become unjammed, so that the driving member slips freely past the sprag and little counterclockwise torque (other than that associated with the slippage) is transmitted from the driving to the driven member.

The design choice of the cam angle



The Two- and Three-Dimensional Designs are similar in their basic principles of operation. However, the angle f and the radius of curvature R_2 in the three-dimensional design are additional degrees of design freedom that can be exploited to enhance performance.

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(θ) is a compromise between two considerations:

1. For a given value of the coefficient of friction, the jamming forces and frictional forces available for transmission of torque increase with decreasing θ. Thus, by making q smaller in a given design, one can increase the maximum locking torque. Alternatively, one can decrease θ to obtain the same locking torque at a lower coefficient of friction; this is desirable if the sprags are to be lubricated (as they usually are).
2. The increase in jamming forces with decreasing θ is accompanied by increased contact forces, stresses, and deformations. The contact stresses and deformations can become excessive. It can become necessary to design the driven member to be radially thicker and/or axially longer to withstand the stresses and reduce the deformations.

The compromise value for θ in a typical design is about 6°.

In the three-dimensional version, the contact surfaces on the sprag are convex chamfers, while the mating contact surfaces on the driving and driven members are the sides of grooves that have truncated-V-shaped cross sections. The sides of the grooves lie at angle ϕ with respect to vertical. The radius of curvature (R_2) of the convex chamfered surfaces of the sprag at the point of contact can be chosen independently of the roll radius (R_1).

One can exploit ϕ and R_2 in various combinations to obtain improvements in one or more of the following ways:

1. One can choose $R_2 >> R_1$ to minimize contact stresses.
2. Like a decrease in θ, a decrease in ϕ causes an increase in frictional forces available for transmission of torque and in the associated contact forces and deformations. One can exploit this effect to increase the maximum locking torque, to achieve the same maximum locking torque while using a more slippery lubricant, or to achieve the same maximum locking torque while increasing θ to reduce contact stresses.
3. The driven member in the three-dimensional configuration inherently resists deformation by contact forces better than does the driven member in the two-dimensional configuration. Thus, less thickening and/or lengthening is needed to effect any reinforcement that might turn out to be necessary.

This work was done by John M. Vranish of **Goddard Space Flight Center**. *For further information,* ***write in 56*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center; (301) 286-7351. Refer to GSC-13617.

One-Time-Opening Miniature Isolation Valves

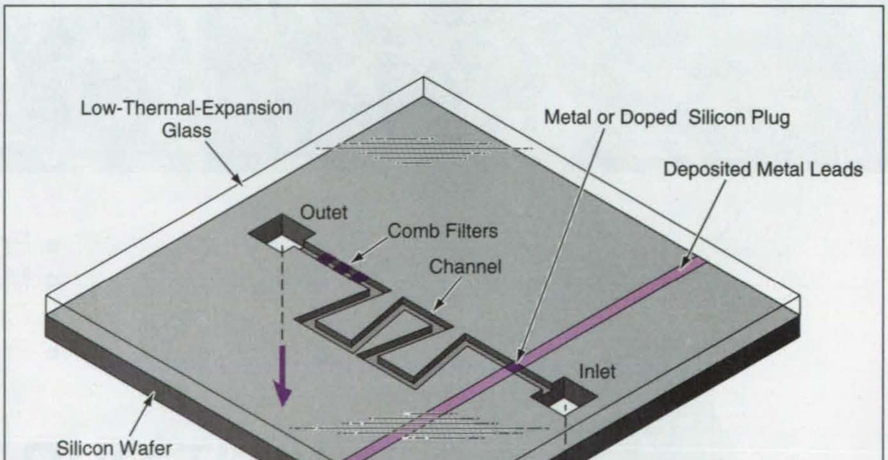
These valves would replace larger, pyrotechnically actuated valves.

NASA's Jet Propulsion Laboratory, Pasadena, California

Miniature electrically actuated, one-time-opening isolation valves for turning on small flows of pressurized gases have been proposed to replace larger pyrotechnically actuated, one-time-opening isolation valves that weigh at least 150 g apiece. The proposed valves would not generate large pyrotechnic shocks, would weigh only a few grams apiece, and would fit on chips no larger than 1 cm^2. The valves would be made mostly of silicon, by use of some of the same techniques used to fabricate integrated electronic circuits.

The figure illustrates a typical valve of this type. A channel would be etched into a silicon chip. A metal or doped silicon plug would be placed at one location along the channel to obstruct flow until the desired time of opening. Metal electrical leads would connect the plug with a valve-opening electrical circuit. To open the valve, the circuit would supply enough electrical current to melt and/or vaporize the plug.

The pressurized upstream gas released by melting and/or vaporization of the plug would carry the plug debris downstream. The channel downstream of the plug would have to be configured so that these debris could condense harmlessly on valve surfaces, without forming a new plug that would block the flow, and without contaminating the gas leaving the valve. For example, the channel could be made in a zigzag pattern as shown in the figure, so that the plug material would tend to condense at the corners where the channel changes direction. Other channel configurations will be explored. The downstream portion of the channel should be widened to prevent clogging by condensed plug debris. Comb filters should be placed downstream of the



The **Plug Would Block the Channel** until melted by electrical current supplied via the metal leads.

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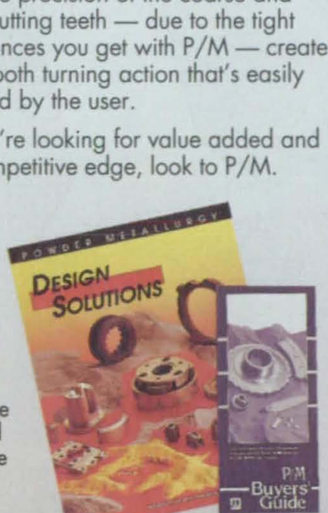

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condensation region to catch free particles of condensed plug material. Optionally, one could include several parallel channels downstream of the plug to decrease resistance to flow.

The valve could be made as a discrete device or integrated with other flow components on the silicon chip. The chip could be encapsulated in a metal case fitted with tube connectors.

This work was done by Juergen Mueller, Lilac Muller, and Thomas George of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 17*** *on the TSP Request Card.*
NPO-19927

Stepped Brush Seals Would Balance Axial Thrust

Marshall Space Flight Center, Alabama

Brush seals between the rotor and stator in a gas turbine would be designed to balance axial thrust, according to a proposal. In typical application, the outer diameter of the rotor would be stepped at upstream and downstream sealing locations to engage brush seals. The sealing brushes would be mounted in the stator and would be similarly stepped on their inner diameters. The steps on the rotor and on the brushes would be dimensioned and positioned so that more brushes would be engaged and/or the brushes already engaged would be bent more with increasing axial displacement of the rotor from a nominal central axial position. Thus, the brush/rotor engagement would resist increasing axial displacement with increasing force. The edges of the steps on the rotor would be chamfered to facilitate engagement and prevent excessive bending upon engagement or reengagement. If necessary, stiffeners could be installed between brushes; these stiffeners would be, essentially, springy washers with inner diameters somewhat larger than those of the brushes.

This work was done by Mark S. Schroder of United Technologies Pratt & Whitney for **Marshall Space Flight Center**. *For further information,* ***write in 23*** *on the TSP Request Card.*
MFS-28944

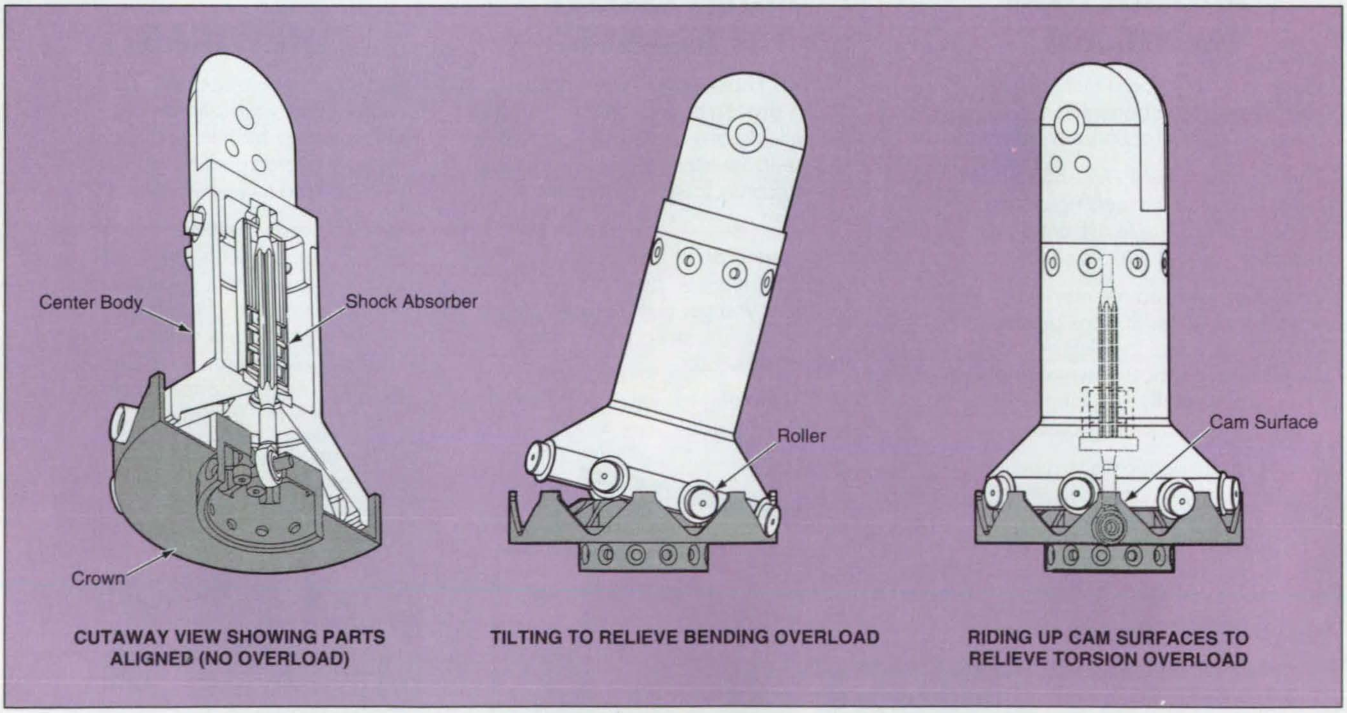
Device Alleviates Bending and Torsion Loads

Sliding friction dissipates excess energy and spring tension provides automatic reset.

Lyndon B. Johnson Space Center, Houston, Texas

A device limits the bending and torsion loads that can be transmitted between two structural components. It also dissipates the excess kinetic and potential energy introduced by overloads and then resets itself.

The device (see figure) includes a center body attached to one structural component and a crown attached to the other structural component. The center body and crown are joined along their common axis of symmetry by a shock



A **Spring in the Shock Absorber** yields, allowing the center body to (1) tilt on the crown to relieve a bending overload or (2) ride up (and, if necessary, slip over the tops of) the cam surfaces on the crown to relieve a torsion overload.

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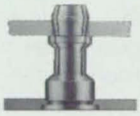

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absorber. An axial-preload spring removes any backlash and acts to maintain alignment by pulling the center body and crown together. In the absence of an overload, the center body and crown remain aligned, with rollers on the outer circumference of the center body resting at the bottoms of V-shaped cam surfaces in the crown.

When a bending load greater than a preset limit is applied between the two structural components, the center body tilts on the crown and the shock absorber becomes stretched, relieving the load. When the applied bending load returns to a value below the preset limit, the spring on the shock absorber pulls the center body and crown back into alignment, and friction in the shock absorber dissipates the excess energy.

When a torsion load greater than a preset limit is applied between the two structural components, the rollers on the center body ride up the cam surfaces on the crown and the shock absorber becomes stretched, relieving the load. When the applied torsion load returns to a value below the preset limit, the spring on the shock absorber pulls the center body back down, so that the rollers become reseated at the bottoms of the cam surfaces. As in the case of bending, friction in the shock absorber dissipates the excess energy.

This work was done by Horacio M. de la Fuente, Michael C. Eubanks, and Tony X. Dao of **Johnson Space Center**. *For further information,* ***write in 58*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center ; (713) 483-4871. Refer to MSC-22515.

Micromachined Cryogenic Capacitive Pressure Transducers

Capacitor dimensions can be selected to tailor resolutions and dynamic ranges.

NASA's Jet Propulsion Laboratory, Pasadena, California

Miniature capacitive pressure transducers are undergoing development for use at temperatures as low as a few Kelvins. These transducers are made from single-crystal silicon wafers by micromachining techniques like those used to fabricate integrated circuits.

The measurement principle involves the use of two slightly separated diaphragms with electrodes on their surfaces (see Figure 1). Changes in pressure cause changes in the deflections of the diaphragms and, consequently, changes in capacitance between the electrodes. The capacitances in transducers of this type ordinarily range from a few to a few tens of picofarads; such capacitance values are readily measurable.

In the original application that prompted the development of these transducers, there was a need for performance superior to that of the best low-temperature pressure transducers then commercially available. Whereas the state-of-the art resolution of capacitive pressure transducers was 1 part in 10^8, the required resolution was 1 part in 10^9 in pressure at a temperature of 4.2 K, with a pressure range of 10 bar (1 MPa). Requirements like these can be satisfied by using micromachining techniques to set capacitor gaps, diaphragm thicknesses, and other dimensions and thereby tailor dynamic ranges and shorting pressures (the shorting pressure of a transducer is the pressure that is sufficient to push the electrodes together and thereby short-circuit the capacitor). For maximum resolution, the shorting pressure should be close to the anticipated value of the pressure to be measured (see Figure 2).

Each diaphragm for a transducer of this type is fabricated from a thin silicon membrane. A shallow well is etched on one side of each diaphragm. By a micromachining process that includes photolithography and evaporative deposition of metal, a metal circular electrode is formed in the middle of each well,

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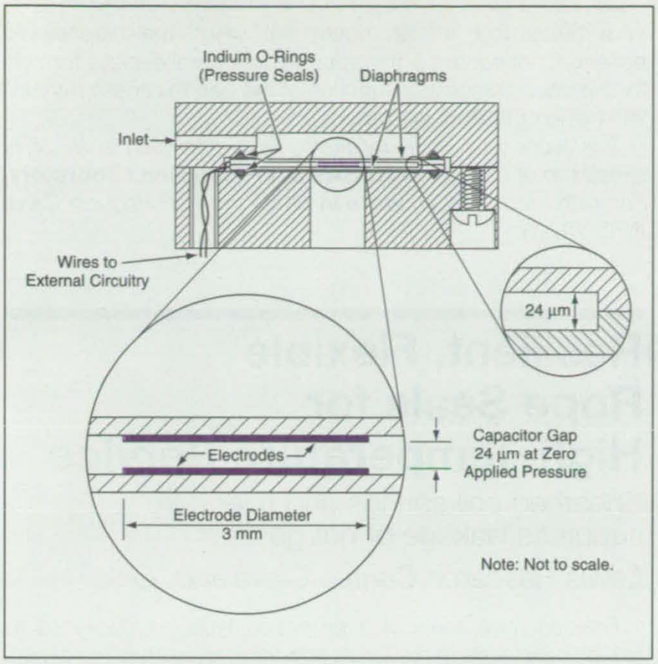


Figure 1. **The Deflection of the Diaphragms** under applied pressure changes the capacitance between the electrodes. Optionally, to provide a reference capacitance, an identical pair of diaphragms with electrodes (omitted from this view for the sake of clarity) can be placed under the diaphragms shown here.

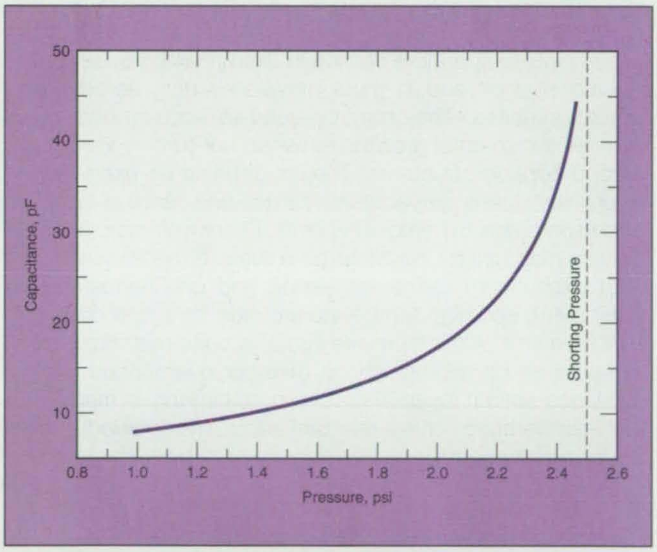
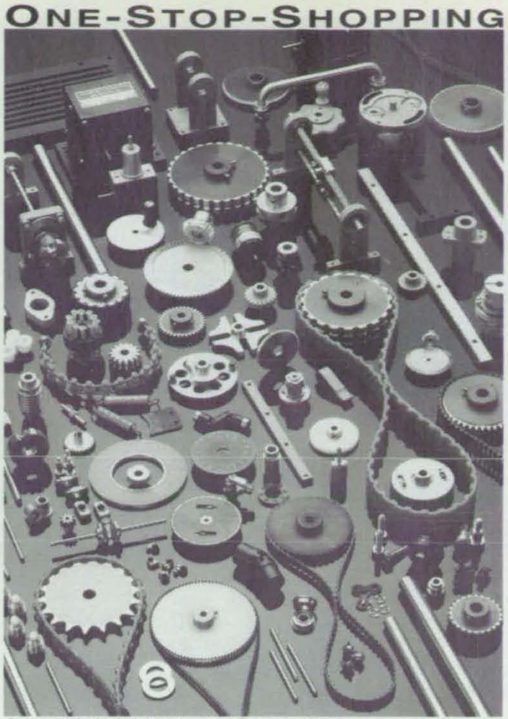


Figure 2. This **Calibration Curve** of a prototype micromachined capacitive pressure transducer was obtained from measurements on helium vapor in equilibrium with helium liquid at known temperature. Note that the rate of change of capacitance with pressure, and thus the resolution of the transducer, is maximum near the shorting pressure.

along with a radial metal conductor that leads to the external capacitance-measuring circuitry. In assembling the transducer, the diaphragms are stacked together with their wells facing each other, so that the sum of depths of the wells closely approximates the capacitor gap in the absence of pressure on the diaphragms. Applied pressure deflects the diaphragms toward each other, decreasing the capacitor gap and thus increasing the capacitance. Typically, a well is about 12 µm deep, so that a zero-pressure gap between electrodes is about 24 µm.

Typical diameters of the electrodes and diaphragms are 3 and 25 mm, respectively. With these diameters, the electrodes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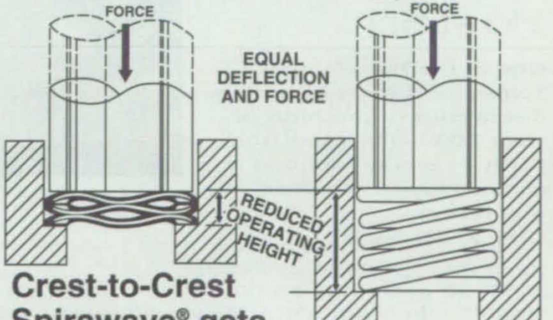
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in a transducer remain nearly flat when the diaphragms deflect. Consequently, the approximate parallel-plate formula for the capacitance as a function of the gap thickness remains valid when pressure is applied.

This work was done by Pierre M. Echternach and Ulf E. Israelsson of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 68*** *on the TSP Request Card.* *NPO-19703*

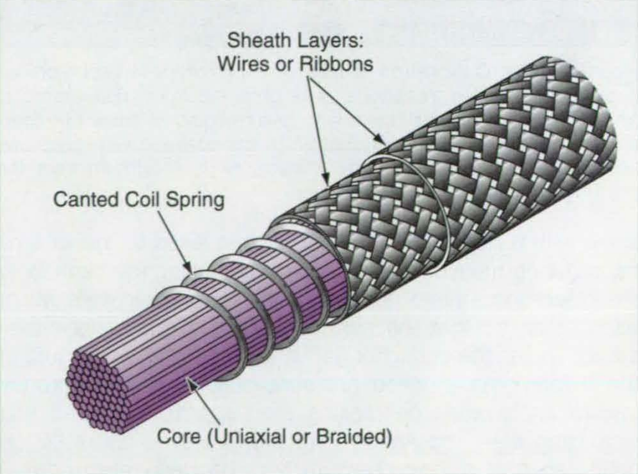
Resilient, Flexible Rope Seals for High-Temperature Service

Sheathed coil springs and fiber core suppress leakage of hot gases.

Lewis Research Center, Cleveland, Ohio

Braided rope seals of a proposed type are designed to exhibit new levels of resilience and flexibility, with minimal permanent set and minimal hysteresis. These rope seals maintain sealing action in the presence of (1) irregularity of the surfaces to be sealed and (2) thermal and mechanical variations of the gaps between the surfaces. These seals are similar to the ones described in "High-Temperature, Flexible, Fiber-Preform Seals" (LEW-15085), *NASA Tech Briefs*, Vol. 17, No. 2 (February, 1993), page 75. They are intended especially for use in high-temperature service in aircraft and ground-based turbine engines and in gaps between sliding aerodynamic control surfaces. They may be used to accommodate and seal relative thermal growths between hot turbine vanes and shroud support structures. They might also be used to seal doors for passenger access, cargo, and landing gear on supersonic and hypersonic aircraft. Other commercial applications may include industrial-tube seals, furnace-door seals, heat exchangers, glass-processing and continuous-casting equipment, and high-temperature molds, amongst others.

A rope seal of this type (see figure) is constructed of a central core and a resilient spring member overbraided with at least one sheath layer. The canted coil spring is made of a high-temperature, creep-resistant alloy. The braided sheath layers are made of wires or ribbons of a high-temperature,



A **Rope Seal for High-Temperature Service** is built around a canted coil spring. The core reduces leakage and resists crushing. The sheath reduces leakage and contributes to resilience and flexibility.

oxidation-resistant superalloy. If the seal were expected to be exposed to limited scrubbing, then the sheath could alternately be braided of ceramic fibers. The spring provides stiffness and load-carrying capacity. It accommodates the large deflections that occur in many sealing applications. Braided, tightly packed sheath elements suppress both the flow of gas through the rope seal and leakage past the contacts between the rope seal and adjacent surfaces. To resist leakage further, the space between adjacent coils can be filled by windings of ceramic/metal fibers or with other packing material.

To enable the rope seal to resist large crushing loads, a core comprised of axial filaments or a braided structure is inserted in the coil spring. These filaments are made of any material capable of withstanding the anticipated combination of crushing loads, high temperatures, and oxidizing atmospheres.

The resilience and flexibility of the rope seal permit the seal to accommodate tight bends without lifting away or kinking.

This work was done by Bruce M. Steinetz of **Lewis Research Center** *and Lawrence A. Kren of Modern Technologies Corp. For further information,* ***write in 11*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Lewis Research Center, Commercial Technology Office, Attn: Tech Brief Patent Status, Mail Stop 7–3, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16231.

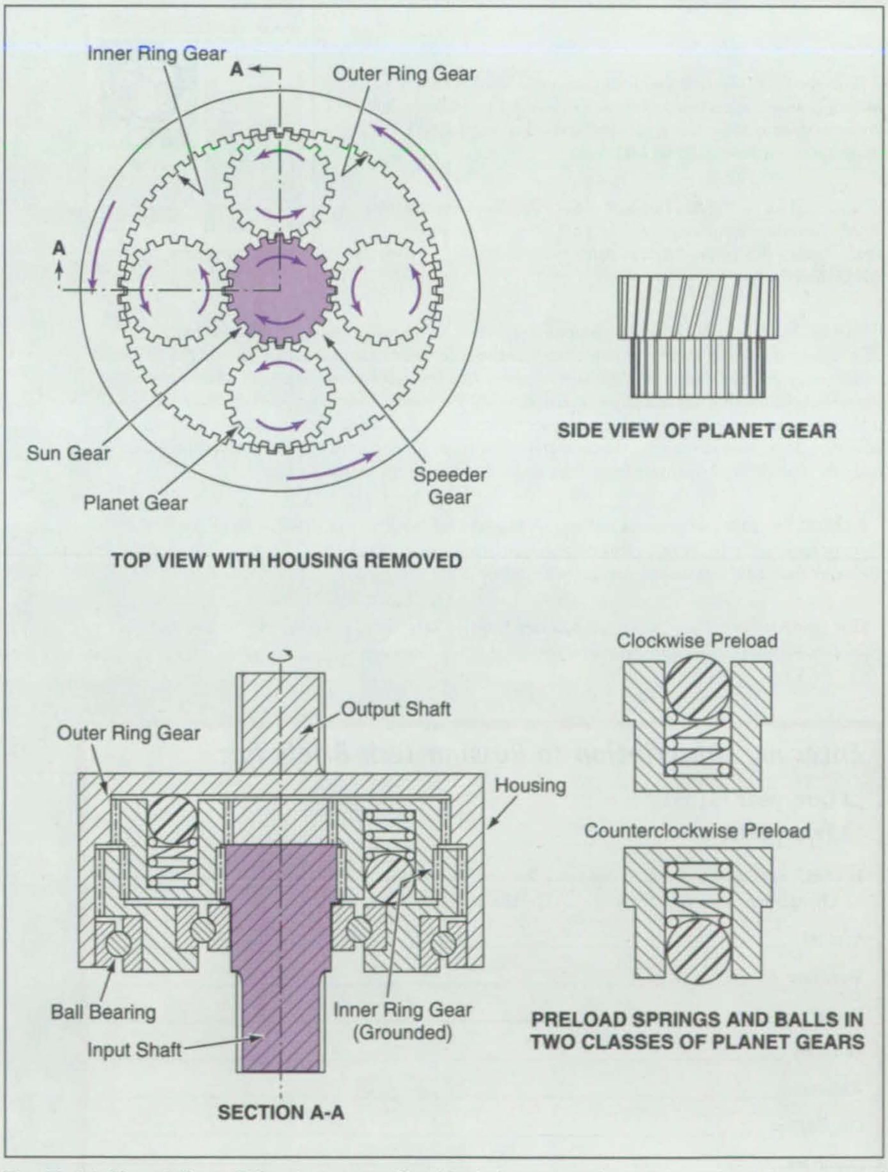
Twist Planet Gear Drive

Features include antibacklash action and high torque multiplication.

Goddard Space Flight Center, Greenbelt, Maryland

The twist planet gear drive has been invented to combine the best performance characteristics, while eliminating the disadvantages, of both harmonic and conventional planetary gear drives. "Twist" refers to the manner in which forces act on the planet gears during operation, as explained below. The twist planet gear drive is related to the antibacklash, high-torque-multiplication mechanism described in "Carrierless Antibacklash Planetary Gear Assembly" (GSC-13608), *NASA Tech Briefs*, Vol. 20, No. 7 (July, 1996), page 28. The twist planet gear drive is also an antibacklash, high-torque-multiplication, carrierless planetary gear drive, and it functions similarly in several respects. However, the planet gears in the twist planet gear drive are made in one piece, whereas those in the other drive are made in two pieces. As a result, the twist planet gears can be made smaller and stiffer, leading to improved torque-transmission and antibacklash performance.

The figure illustrates one of several versions of the twist planet gear drive. The drive includes an inner ring gear that is grounded; that is, fastened to an external structure to hold it stationary. An input shaft turns a sun gear, rotating in ball bearings in the inner ring-gear structure. There are four planet gears spaced apart at equal angles. Each planet gear has two sets of teeth; a lower set of straight teeth and an upper set of helical teeth with a somewhat greater pitch radius. The straight teeth engage both the sun gear and the inner ring gear. Thus, the sun gear drives the planet gears, causing them to rotate and to travel around the inner ring gear.



The **Twist Planet Gear Drive** has an antibacklash feature and combines the advantages of harmonic and conventional planetary gear drives.

The helical teeth on the planet gears engage both a speeder gear collinear with the sun gear and an outer ring gear, which is mounted in a housing connected to the output shaft collinear with the input shaft and sun gear. The speeder gear serves to react forces in such a way as to prevent the planet gears from being pushed inward or tilted when a load is applied.

When the sun gear turns clockwise, for example, the planet gears rotate counterclockwise while orbiting clockwise around the common input/output shaft axis. The counterclockwise rotation of the planet gears is transmitted to the outer ring gear and thus to the output shaft. However, the counterclockwise motion of the upper annular gear is reduced by the clockwise orbiting motion of the planet gears, so that the net rotation of the output shaft is much slower than the rotation of the input shaft, and the output torque is multiplied accordingly. The entire drive train is very efficient, involving essentially rolling friction. The speed-division factor, which equals the torque-multiplication factor in the case of zero friction, is given by speed in/speed out = $2R_{pl}(R_s + R_{pl} + R_{pu})/[R_s(R_{pl} - R_{pu})]$, where R_s denotes the pitch radius of the sun gear and R_{pl}, and R_{pu} denote the pitch radii of the lower and upper sets of teeth, respectively, on the planet gears.

Although the output shaft turns oppositely to the input shaft in this version, it can be made to turn in the same direction in a different version. As indicated in the equation above, the sign of the speed-reduction and torque-multiplication factor (and thus the direction of output rotation) can be changed by making the pitch radius of the upper teeth on the planet gears smaller instead of larger than that of the lower teeth. Of course, this would also necessitate accommodating changes in the sizes of the other gears.

Each planet gear is axially preloaded against the inner flange surface of either the stationary structure that supports the inner ring gear or else the outer housing connected to the output shaft. The axial preload is supplied by a compression spring and a plastic ball located in an axial bore. The reaction of the preload via the helical gear teeth causes the planet gears to twist slightly to the limit of the slack between the planet gears and the gears with which they are engaged; this action eliminates backlash. The helical teeth are pitched at an angle of about 6° from the axis. This small helix angle is a locking angle in the following sense: When the output shaft encounters opposing torque, frictional forces between mating teeth build up faster than do forces that tend to counterrotate the planet gears. As a result, the mating helical gear teeth remain locked together in the relative position of initial contact.

To compensate for backlash in both clockwise and counterclockwise rotation, it is necessary to provide planet gears with opposed preloads; that is, with each planet gear biased axially in the direction opposite that of its nearest neighbors. It is also necessary to use an even number of planet gears, the minimum being four as shown in the figure, because only half the planet gears are transmitting torque at any given time.

This work was done by John M. Vranish of **Goddard Space Flight Center** *and Steve Gorevan of Honeybee Robotics, Inc. For further information,* ***write in 49*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center; (301) 286-7351. Refer to GSC-13621.

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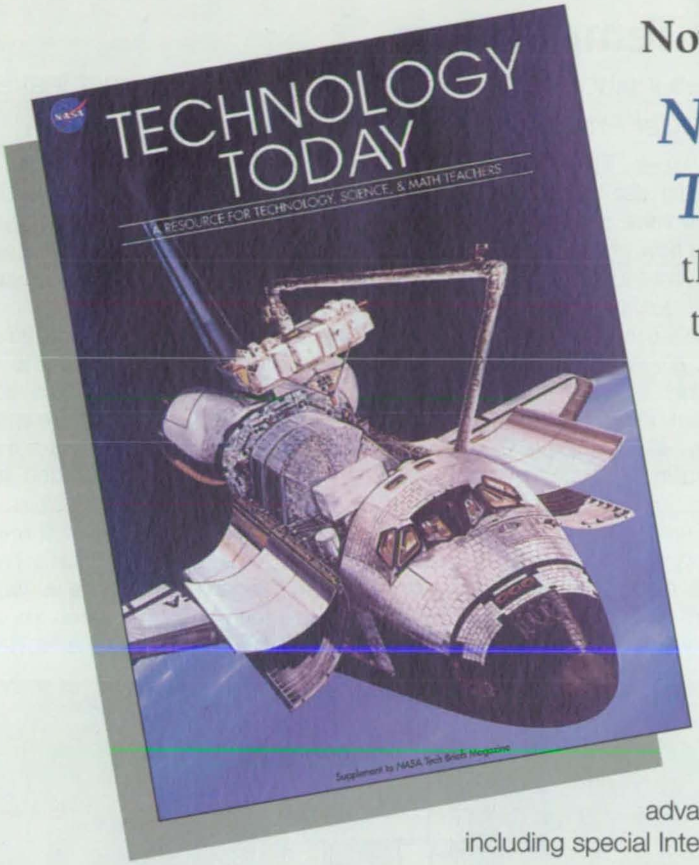

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MTB297

Magnetostrictive Valve for Use at Low Temperature

Features include remote controllability and little heat leakage.

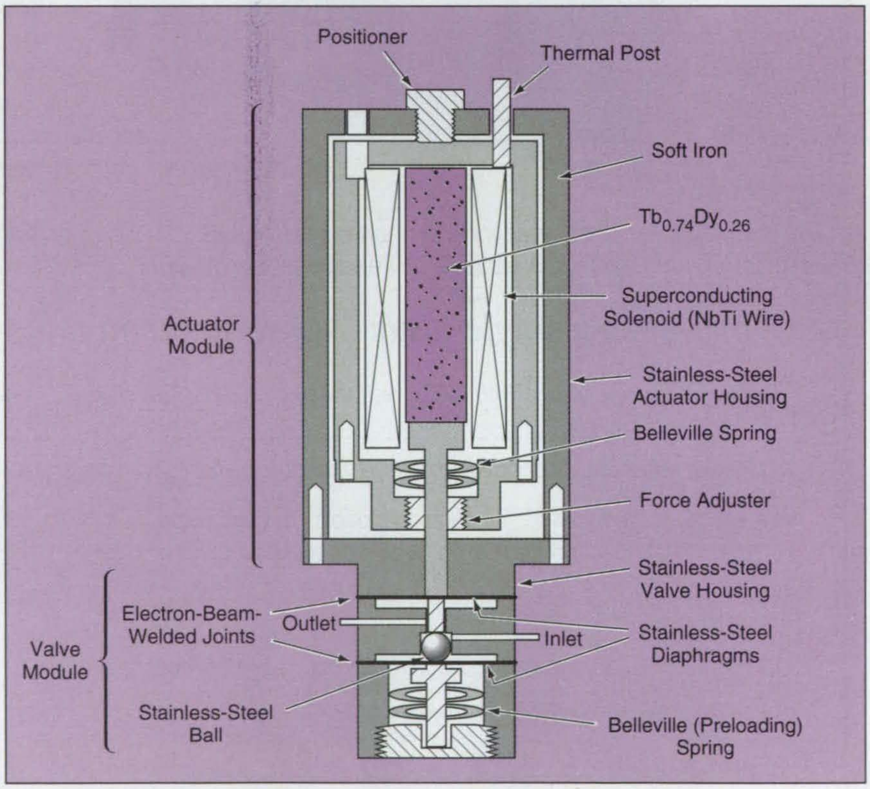
NASA's Jet Propulsion Laboratory, Pasadena, California

The figure illustrates a valve designed for use in a cryogenic apparatus. The valve provides remote control of the flow of liquid helium or other fluid and contributes minimally to the undesired leakage of heat into the apparatus. The valve is built in two modules: a valve module and an actuator module.

The main body of the valve module is a stainless-steel housing. The poppet in this valve is a stainless-steel ball contained in a passage between an inlet and an outlet in this housing. This passage is sealed between two stainless-steel diaphragms that are electron-beam-welded to the valve housing. The valve is held normally closed by Belleville preloading springs that push the ball upward against the valve seat in the housing with a force of about 150 lb (about 670 N).

The valve is opened by use of a magnetostrictive actuator that, when actuated, pushes downward on the ball with a force sufficient to overcome the compressive preload and unseat the ball. The magnetostrictive actuator component is made of an alloy of the rare-earth metals terbium and dysprosium in the composition $Tb_{0.74}Dy_{0.26}$. This alloy was chosen because it exhibits a large magnetostrictive effect in the intended operating-temperature range near 4 K. To provide additional flexibility for adjustment of the actuation force, a threaded force adjuster with a second set of Belleville springs is incorporated into the actuator module.

The magnetic field needed to produce the magnetostrictive effect is provided by an electromagnet in which the coil of wire is made of NbTi. The current needed to generate a magnetic field strong enough to open the valve is about 2.3 A. Because the NbTi wire is superconductive at the low operating temperature, there is no electrical heating in the coil to contribute to leakage of heat into the cryogenic apparatus.



Belleville Springs Push the Ball Upward into the valve seat, closing the valve. When the magnetostrictive rod is energized, it pushes the ball downward, unseating the ball and thus opening the valve.

This work was done by Inseob Hahn, John Gatewood, and Martin Barmatz of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 84*** *on the TSP Request Card. NPO-19480*

Industry Leaders

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As the "voice" of the international P/M and advanced particulate materials industries, MPIF serves to promote and support these industries through its many activities. MPIF is recognized as one of the most effective trade associations in the metalworking industry and has been an innovator in standards development, industry development and promotion, and technology transfer in the form of conferences, seminars, and publications.

Powder metallurgy and particulate materials are vital to the success of products such as passenger cars and light trucks, jet turbine engines, cutting tools, home appliances, computer peripherals, and medical equipment. The P/M industry has grown dramatically within the last decade and like MPIF, has enjoyed a synergistic relationship among metal powder, equipment, and P/M parts and specialty products suppliers.

No longer considered a substitute or second-class process, powder metallurgy is the first and sometimes the only choice to form precision, high-performance products operating in demanding applications. The typical U.S.-produced family vehicle contains almost 30 pounds of P/M parts, a figure that will grow to more than 40 pounds by 2000. Through the end of 1996, more than 75 million powder-forged (P/F) connecting rods have been produced and used in GM, Ford, and Chrysler auto engines. This single application has proved P/M's long-term reliability more than any other product.

The metal injection molding (MIM) sector of the P/M industry is expanding with major markets in medical, firearm, and business machine applications.

The growth of advanced particulate materials will continue well into the 21st century. These products include composites, intermetallics, metal fibers, high-speed steels, coated binder powders, submicron powders and processes such as hot isostatic pressing, spray forming, plasma spraying, and mechanical alloying. New applications for these materials and processes include automobiles, aircraft engines, electronic packaging, sporting goods, computer peripheral equipment, and medical markets.

Prospects for P/M's future look very promising as design engineers select powder metallurgy as a way of producing innovative products more efficiently than with other metal forming processes.

For more information, contact: Metal Powder Industries Federation, 105 College Road East, Princeton, NJ 08540-6692; Tel: 609-452-7700; Fax: 609-987-8523; http://www.mpif.org/mpif.

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NTB297

Variable-Compliance Wrist for Robotic Manipulator

Springs and cables give compliance, while nesting cones limit the range of compliant motion.

Goddard Space Flight Center, Greenbelt, Maryland

A robot wrist (see figure) provides a variable-compliance joint between the robot arm and its end effector. The manipulator can thus be adapted to a variety of tasks; for example, insertion of an object into a cavity with a precise fit.

Upon activation by the user, the wrist can be made rigid in a precisely chosen orientation, or can be made compliant within precisely chosen boundaries. Hard constraints limit the range of compliant motion. If power is lost, the wrist reverts to a passive mode of constrained compliance or precisely rigid orientation or retains its current mode (rigid or compliant), at the user's option.

Older designs of active and passive mechanical wrists do not provide both compliance and rigid, precise orientation of the end effector. Older strategies for active control do not provide a choice of rigid orientation or compliance on loss of power; moreover, they require extensive computational hardware and software, which add to the complexity and cost of the manipulator and reduce its reliability.

The wrist includes a linear actuator (a piston or a lead screw driven by an electric motor), and three parallel connected machined plates: a tool plate, a docking plate, and an anchor plate. Three short axial cables of the same length connect the tool plate and the anchor plate so that, when they are fully extended, the cables make the two plates parallel when their longitudinal axes (which are perpendicular to the planes of the plates) coincide laterally (with respect to displacement in the plane of either plate). The cable connection points on the tool and docking plates are spaced 120° apart in a triangular pattern centered on the longitudinal axis of each plate.

The radial distance of the anchor-plate cable-connection points from the longitudinal axis of the anchor plate differs from the radial distance of tool-plate cable connection points from the longitudinal axis of that plate. This difference in radius causes the tool plate to appear to rotate about a remote center located on the longitudinal axis of the anchor plate whenever the tool plate is displaced perpendicularly to the longitudinal axis of the anchor plate. The wrist thus exhibits a remote center compliance.

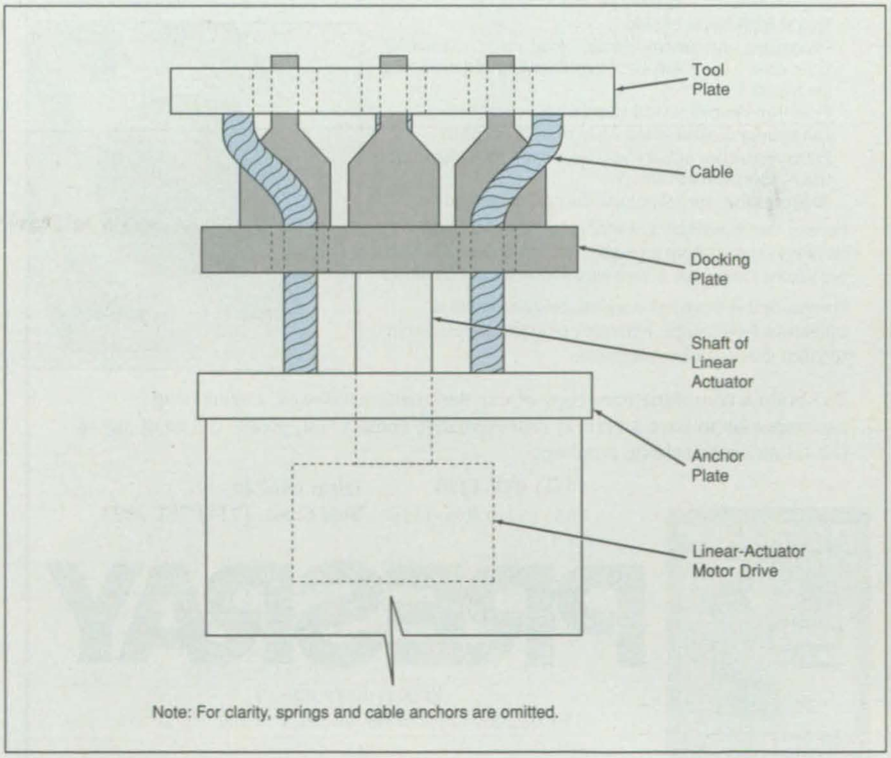
Between the anchor plate and the tool plate is the docking plate, which is coaxial with and parallel to the anchor plate. The three cables pass freely through holes in the docking plate. The linear actuator connects the docking plate to the anchor plate.

When the tool plate and the anchor plate are forced together axially by the linear actuator, three cones on the docking plate fit snugly into three mating holes in the tool plate. The wrist is then rigid.

When the linear actuator separates the tool and docking plates by a distance less than the height of the cones, the joint becomes compliant, but its lateral and rotational motion is limited because the tips of the cones still extend into the mating holes in the tool plate, thus providing hard stops. The limits on the motion are determined by the extent of penetration of the cones into the holes. When the tool and anchor plates are separated axially by more than the height of the cones, short cylindrical tips on the cones still extend through the mating holes to provide hard stops.

Three springs, coaxial with the three cables, keep the docking plate separated from the tool plate unless they are compressed by the linear actuator. In so doing, the springs also tend to resist longitudinal motion of the tool plate toward the anchor plate. In addition, they resist lateral motion of the tool plate relative to the docking and anchor plates. The cables provide further axial and lateral restoring forces in bending and buckling. The springs and cables thus create compliance, while the cones ensure precise limits to the compliant motion.

This work was done by Mark Jaster of **Goddard Space Flight Center** *and Kenneth A. Knowles, Jr., of McDonnell Douglas Space Systems Co. For further information,* ***write in 69*** *on the TSP Request Card. GSC-13507*



This **Robot Wrist**, shown here in simplified form, can be made rigid or compliant within a limited range of motion.

Portable Drilling Apparatus for Subsurface Sampling

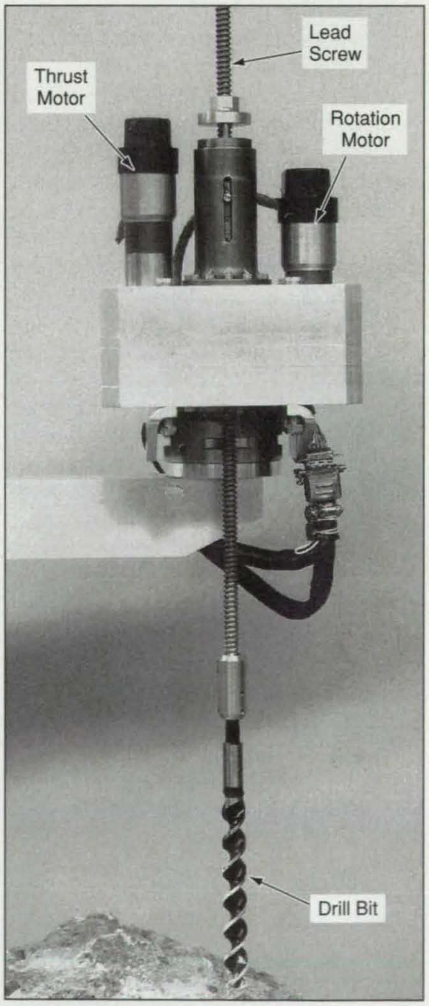
Materials that could be sampled include ice, snow, and sand.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure illustrates a prototype of a special-purpose compact, lightweight robotic drilling apparatus that would be flown to an asteroid or comet and used to acquire samples of subsurface material at depths of as much as 1 m. Terrestrial versions of the apparatus could likely be designed for remotely controlled sampling of snow, ice, sand, soil, and soft rock at the same or greater depths in inaccessible locations and in such hazardous locations as toxic-waste dumps. The prototype is capable of a maximum axial translation speed of 3.5 mm/s at an axial thrust of 130 N, and a maximum rotational speed of 45 r/min at a torque of 2.25 N·m.

Unlike some older mechanisms for sampling by drilling, this apparatus does not include a large, massive drill tower with linear bearing slides for axial translation of the drill. Instead, the drill is translated axially by use of a relatively compact lead-screw mechanism, and the lead screw is an integral part of the drill stem. The depth of the hole that can be drilled is thus limited only by the length of the lead screw that can stand unsupported.

The apparatus includes a compact thrust-and-rotation mechanism that contains two drive motors, by means of which the rotation and the axial translation of the drill can be controlled separately. One motor supplies rotation and torque to the drill through a pair of



The **Prototype Drilling Apparatus** is relatively compact and lightweight. It contains two drive motors and sensors that, together with an external control computer, provide control of axial and rotational drill motions and loads.

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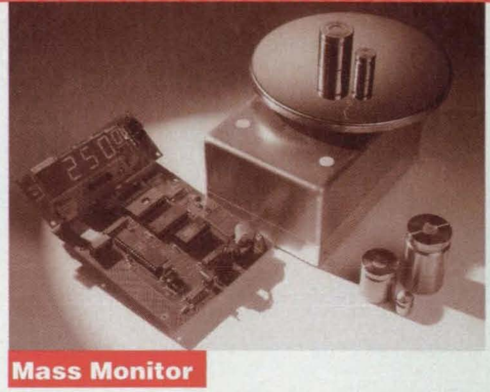

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keyways cut along the length of the lead screw. The other motor rotates a lead-screw drive nut to impart axial translation and thrust. Because of the kinematic coupling between the two motor drives via the lead-screw thread, the speed of the thrust motor must be coordinated with that of the rotational motor to achieve the desired translation speed. Force and torque sensors, plus integral position encoders in the motors, provide feedback for use in closed-loop control of translation, rotation, torque, and/or thrust.

The apparatus also incorporates a percussion drilling mode. The percussive motion is generated with the help of a saw-tooth cam that is keyed to the screw shaft. As the cam is rotated, a spring-loaded mass is lifted and released against the lead-screw drive nut, and the resulting percussive force is transmitted through the drive nut and lead screw to the drill tip.

The planned design of the drill bit is not shown, but is composed of three parts: a twin-fluted section with a quick-release end, a drill-bit body, and a swiveling bit head. Drilling is performed by both carbide cutters and indentors in the drill head. The head is able to swivel 90° to open two sample chambers in the drill body. By rotating the drill in reverse, the head swivels open and the chambers are filled. The drill rotates forward to close the chambers, and the drill body, with the sample enclosed, is brought to the surface. The bit is placed inside the science instrument, allowing the drill to pick up another drill body for further drilling and sampling.

Closed-loop control is implemented by an external computer. For example, in force- or torque-control drilling, the outputs of the force or torque sensors are fed to the computer, where they are processed by automatic-control software, to control axial translation or rotation to maintain a constant axial thrust or torque load. The ability to do this is particularly important, given the wide-ranging material properties that could be encountered. The outputs of the force and torque sensors can also be used to detect trouble in drilling automatically; for example, to indicate that excessively hard material has been encountered, making it advisable to move to a new sampling site.

This work was done by Donald R. Sevilla, Richard V. Welch, and Albert J. Delgadillo of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 22*** *on the TSP Request Card. NPO-19908*

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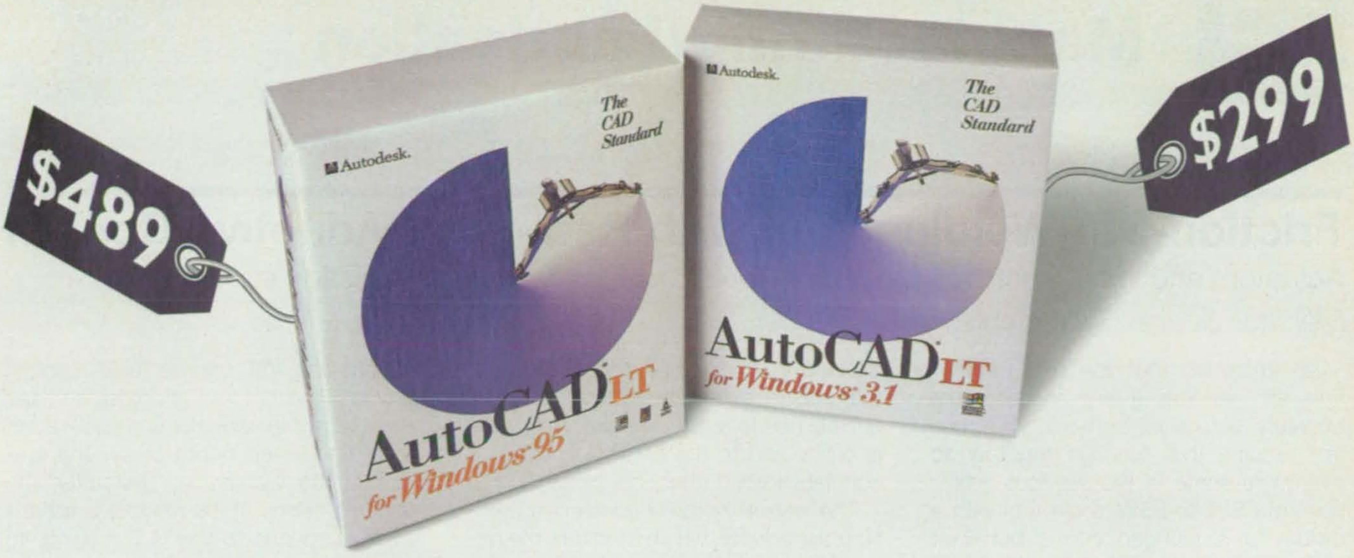

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Manufacturing/Fabrication

Friction-Stir-Welding Tool With Real-Time Adaptive Control

Actuators and instrumentation overcome some previous limitations of friction stir welding.

Marshall Space Flight Center, Alabama

An improved machine tool for friction stir welding (FSW) incorporates hydraulic actuators, sensors, and control circuitry that function together to overcome some of the previous limitations of FSW. In FSW, a pin tool with a probe tip is plunged into a butt-joint configuration and rotated. The friction of the rotating pin heats the workpiece, plasticizing a column of metal around itself. As the pin-tool moves along the weld joint, it extrudes and forces plasticized metal to its rear, while applying a large downward forging force. The rearward-displaced metal culminates into an integrally solid microstructure characterized by very, very fine ASTM grain size. The FSW process can produce strong, crack-free welds in alloys that tend to crack when fusion-welded. Unlike fusion welding, FSW does not generate fumes or radiation. Also in comparison with fusion welding, FSW is relatively energy efficient.

The present improved machine tool for FSW offers the following advantages over FSW machine tools of older design:

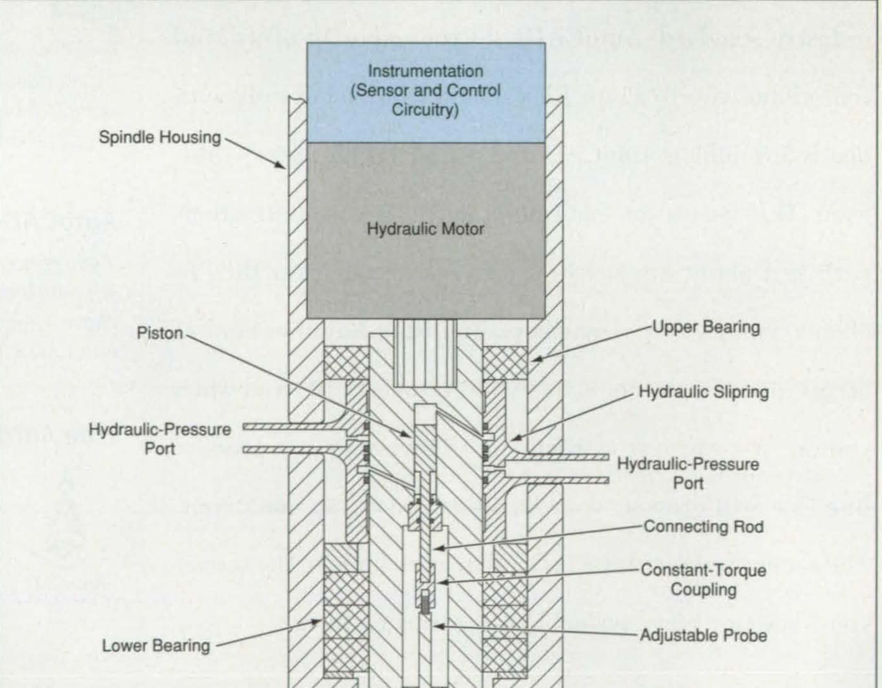
- The same tool can be used to weld different workpieces of different thicknesses, or a single workpiece within which the thickness varies along the weld line.
- It terminates the weld joint without leaving a crater at the end of the tool path.
- It senses surface irregularities and changes in the thickness of the workpiece and adjusts the depth of penetration of the probe tip accordingly.
- It can be used to repair welds, whether made by FSW or conventional fusion welding.

The improved FSW machine tool (see figure) includes an arbor, designed especially for the purpose, that is mounted in a hydraulically driven high-speed machine-tool spindle. The arbor contains a hydraulic cylinder and piston driven via a hydraulic slipring with ports through the spindle housing. The piston drives the probe axially, thus serving as a means to control the depth of penetration of the probe into the workpiece. Although the probe is free to move longitudinally within the pin-tool body under the influence of the piston, it is not entirely free to rotate; instead, the probe is connected to the pin-tool body via a constant-torque rotary coupling.

The spindle housing contains a pressure transducer, which monitors the differential hydraulic pressure across the piston. Also contained within the spindle housing is a vertical locating transducer (VLT), which senses contact between the pin-tool shoulder and the workpiece and monitors the depth of penetration of the tool into the workpiece. The pressure and depth readings are used as feedback signals in a computer-based adaptive real-time control scheme for maintaining the tool at the required depth of penetration, as explained below.

Once the VLT senses initial contact between the pin-tool shoulder and the workpiece, the shoulder is positioned at a predetermined depth below the surface of the workpiece. Thereafter, the vertical position of the pin tool is adjusted, in response to the VLT reading, to keep the shoulder at the prescribed depth. At the same time, the differential pressure across the piston is measured; changes in this pressure can be caused by surface irregularities, distortions, or deviations in the thickness of the workpiece. Whenever the pressure goes outside a prescribed range, a hydraulic valve is actuated to adjust the probe to the appropriate depth.

The tool implements the following sequence of actions to terminate a weld: When the pin tool nears the end of the



The **Hydraulically Actuated FSW Tool** is mounted in a hydraulically driven machine-tool spindle. The probe is moved up and down automatically in response to measurements by pressure and displacement sensors.

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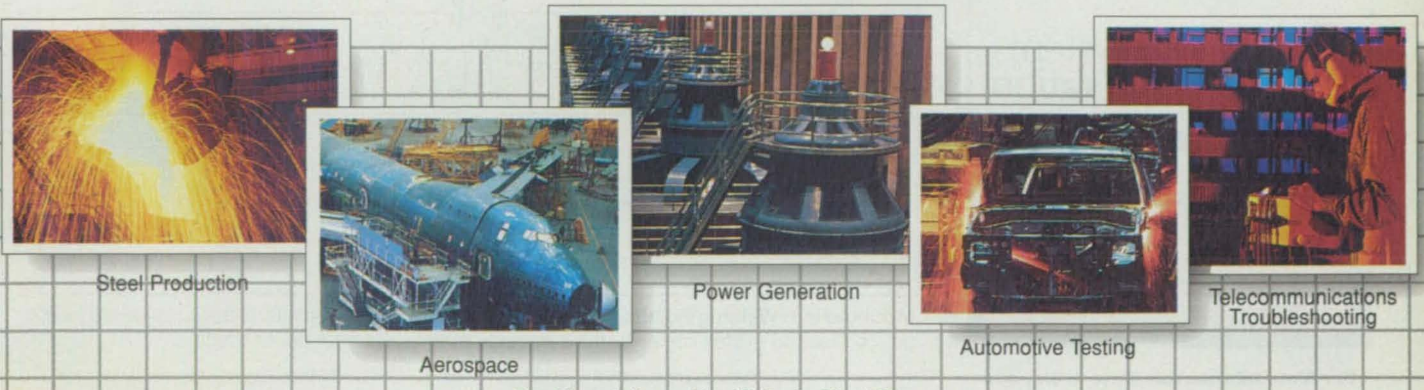

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weld joint, the probe is gradually withdrawn from the workpiece while the shoulder is kept at the required depth. Once the probe has been fully withdrawn, the pin-tool body is slowly withdrawn.

This work was done by Jeff Ding of **Marshall Space Flight Center** *and Peter A. Oelgoetz of Rockwell International Corp. For further information,* ***write in 60*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0026. Refer to MFS-30122.

Back-Side Inert-Gas Shielding Strips for Keyhole Welding

Effective shielding can be obtained with modest setup effort.

Marshall Space Flight Center, Alabama

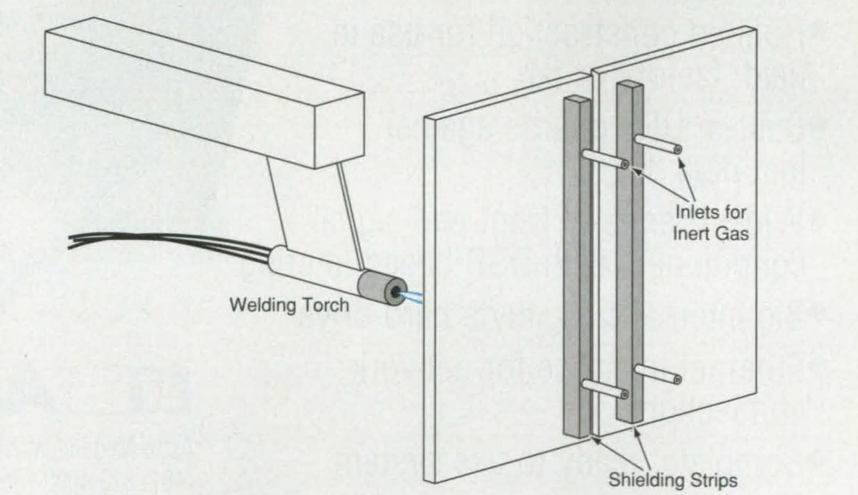
Simple, striplike gas-distributing boxes have been developed to provide inert-gas shielding of the back sides of workpieces during welding in the keyhole (full-penetration) mode. These shielding strips were intended originally for use in variable-polarity plasma arc welding of aluminum/lithium alloys, wherein they create even layers of protective inert gases that blanket the weld joints along their entire lengths, both before the keyholes are formed and during welding. The shielding strips are also adaptable to gas/metal arc welding and gas/tungsten arc welding where back-side shielding is needed.

Unlike some back-side purge boxes and chambers that move in synchronism with welding torches, these shielding strips remain stationary during welding. Consequently, the shielding strips do not involve ancillary position-controlling and position-monitoring equipment and can be mounted on workpieces or welding machines with modest setup effort.

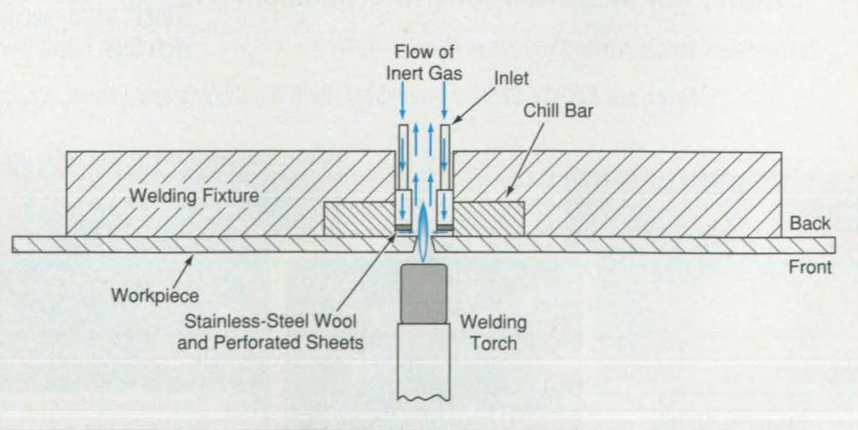
A complete welding setup includes two of the shielding strips mounted between chill bars, on opposite sides of the weld joint. The strips are mounted at a standoff distance of about 1/8 in. (3 mm) from the workpiece to provide gaps for the flows of gas (see figure). The inert gas (typically, argon, helium, or a mixture of the two) flows from a supply tank to inlets on the strips. Inside the strips, the gas diffuses through stainless-steel wool, then flows through perforated sheets that extend along the entire length of the strips. The gas flows out of the strips through the mounting gaps, creating a protective atmosphere along the entire length of the weld joint.

This work was done by Samuel Dwight Clark and Clinton A. Craig of **Marshall Space Flight Center** *and Gerald William Bjorkman, Jr., of General Dynamics. For further information,* ***write in 41*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Marshall Space Flight Center; (205) 544-0021. Refer to MFS-31006.



VIEW WITH WELDING FIXTURE AND CHILL BAR OMITTED



Mounted in a Welding Fixture, the shielding strips blanket the length of the weld joint in inert gas, protecting molten metal on the back side of the weld from contamination.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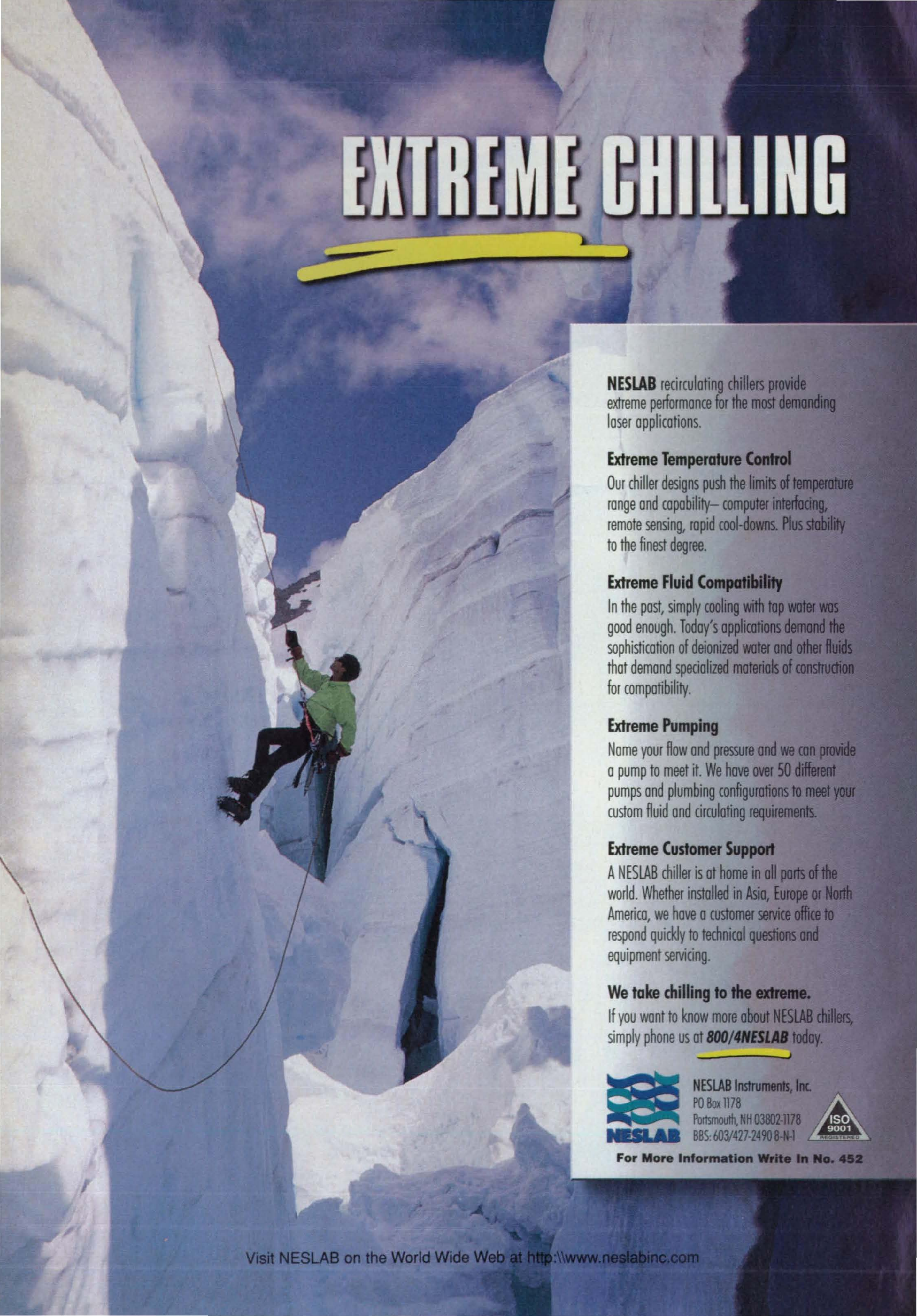

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LASER TECH BRIEFS

Laser Tech Briefs Supplement to *NASA Tech Briefs* February 1997 Issue Published by Associated Business Publications

LASER TECH BRIEFS

4a Improved Stabilization of Delay in an Optical Fiber
6a Alternative for Stabilization of Delay in an Optical Fiber
8a Electro-Optic Beam-Steering Device
9a Tunable Lasers Pumped by Visible Laser Diodes
10a Tip Modules for Fiber-Optic Endoscopes with Radial Views
11a Fixture for Stripping Coatings from Jacketed Optical Fibers

DEPARTMENTS

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13a New Products
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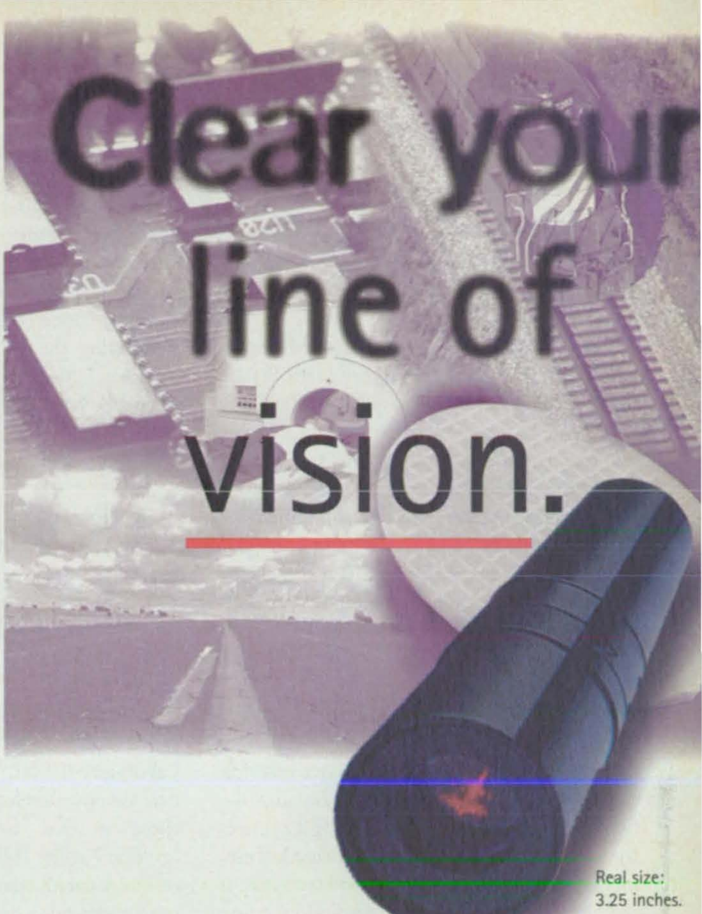
FEATURE

3a Toward an All-Silicon Optical-Electronic Chip

On the cover:

At the Army Research Laboratory, Ft. Belvoir, VA, a team of researchers have created a three-dimensional monochromatic hologram by using a laser to illuminate the object and writing the image into a photorefractive crystal. Another laser then projects the image into a liquid scattering material. The group is currently working on ways to make the grating image permanent in the crystal. Here Dr. Christy Heid, a postdoctoral member of the Sensors and Electron Devices Directorate team, adjusts a lens to bring a 3D hologram of a die into focus. (Army photo by Doug Lafon)



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NEWS BRIEFS

Notes from Industry and the Federal Laboratories

Researchers at the Department of Energy's Oak Ridge National Laboratory (ORNL) are touting an optical microspectrometer they developed as an instrument of innumerable potential uses. Possibilities for the device, about the size of a computer mouse, range from gasoline octane analysis and noninvasive blood chemistry analysis to environmental monitoring, industrial process control, chemical warfare detection, and aircraft corrosion monitoring, according to Slo Rajic, principal developer and a member of ORNL's Engineering Technology Division.

The device, which is made from a special kind of plastic, has multiple precision surfaces that diffract light from a diode laser entering through an optical fiber input. Because the fiber attaches to the unit by way of a connector, it requires no alignment. Another key element setting the microspectrometer apart is the ultraprecise single-point diamond turning fabrication technology developed at ORNL, which produces optics-quality surfaces that need little polishing.

Configured to detect different spectral ranges, the device could be used as a laser warning receiver, for plasma diagnostics, or for wavelength division multiplexing for fiber optic telecommunications systems. "Unlike some of the minispectrometers in use," Rajic says, "this system is not merely a scaled-down version of a larger system. It's a completely new and revolutionary approach."

Other researchers who played a part in developing the microspectrometer are Boyd Evans, Charles Egert, Joe Cunningham, and Troy Marlar. The research was supported by DOE's Laboratory Directed Research and Development fund.

In November of last year Schott Glass Technologies of Duryea, PA, completed the first stage of planned expansion occasioned by its involvement with the Department of Energy's research into inertial confinement fusion. For many years the company has designed and manufactured glasses for large solid-state high-energy laser systems such as the Nova facility at Lawrence Livermore National Laboratory (LLNL) in California. DOE scientists are now developing the next generation of these systems for Livermore's National Ignition Facility (NIF), which will be made up of 192 separate laser beams brought to a common focus on a fuel pellet at the center of a fusion test chamber. NIF's basic design was certified in 1994 with the successful operation of the Beamlet laser, a full-scale prototype of a single NIF beamline for which Schott produced the laser glass. In December the Department of Energy, as expected, officially designated LLNL as the NIF site.

The principal mission of NIF is to insure that the nation's nuclear weapons development is safe and reliable. The signing of the Comprehensive Test Ban Treaty by President Clinton last year halted active testing of nuclear devices. Operation of NIF will also help to validate inertial confinement fusion as an alternative energy source and provide a test-bed for understanding processes at work at the center of the Sun and other stars. The Commissariat a l'Energie Atomique, the French counterpart to the DOE, is designing a similar system called Laser Megajoules (LMJ).

Schott's new building, an extension of present facilities by about 14,000 sq. ft., will be used first for proof-of-concept production and testing of laser glass for NIF and LMJ. A second-phase building of 23,000 sq. ft. is planned for construction this year. Pilot production for NIF is expected to begin in 1998.

The National Institute of Standards and Technology (NIST) and Conductus of Sunnyvale, CA, cooperated in a CRADA to produce an extremely sensitive high-temperature superconducting bolometer for infrared imaging. The device is based on a novel all-epitaxial micromachining technology that combines an yttrium-barium copper-oxide thin film on an yttria-stabilized free-standing zirconia membrane. The NIST-Conductus device attained a sensitivity of 0.6 picowatt per root hertz, far better than helium-cooled or other superconducting bolometers at long infrared wavelengths. The previous record for sensitivity was 1.5 picowatts per root hertz. The device has caught the eye of both NASA and the European Space Agency, who have been seeking a bolometer that is cheaper, easier, and faster.

Resonetics Inc. of Nashua, NH, has received a Phase I Small Business Innovation Research grant from the Cancer Research Center of the National Institutes of Health. For a six-month period, the grant supports investigating the use of excimer lasers for micromachining structured phosphors for electronic x-ray imaging. Such phosphors are critical to radiographic systems under development for digital mammography. Resonetics will use laser ablation to create a fiber optic structure in the phosphor, a controlled process that can yield square pillar structures smaller than 20 × 20 μm on such materials as glass, ceramics, and plastics. The University of Massachusetts Department of Radiology is collaborating on the project.

Resonetics has completed a facility expansion and renovation. Ron Schaeffer, Director of Corporate Development, says the additional space will meet current operating requirements, but plans are to expand to off-site facilities, the first foreseen in California this year.

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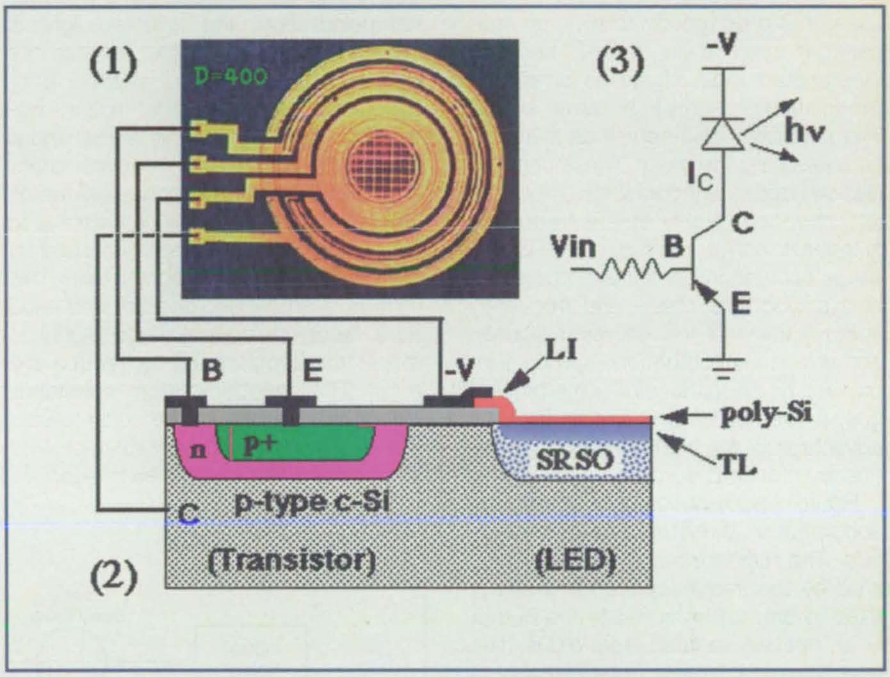
TOWARD AN ALL-SILICON OPTICAL-ELECTRONIC CHIP

Labs at the University of Rochester and the Rochester Institute of Technology (RIT) have turned out a single chip that, for the first time, integrates a porous silicon light-emitting diode (LED) into conventional microelectronic circuitry. The team of engineers responsible labels it an important stride toward an all-silicon system that can process light as well as electricity.

The key element in the integrated chip is a sturdier form of porous silicon that can withstand today's fabrication processes. Philippe Fauchet, leader of the team, professor of electrical engineering and optics at the University, and a senior scientist at its Laboratory of Laser Energetics, points out that in today's manufacturing environment, a silicon wafer travels four or five miles on the factory floor through hundreds of steps in a very expensive fabrication line. "Because of the enormous investment, it's important to adapt any new technology to the fabrication lines already established," he said.

Conventional semiconductor technology is largely based on crystalline silicon, which is an indirect bandgap material. This means that in order to allow a photon to be emitted, the silicon crystal would have to vibrate. Among a number of attempts to solve the problem, one stands out: In 1990 J. L. Canham showed that silicon could emit high-efficiency, room-temperature visible photoluminescence when its surface was made porous through a simple hydrofluoric acid etch. But the extreme reactivity and fragility of porous silicon render it unable to withstand conventional manufacturing techniques.

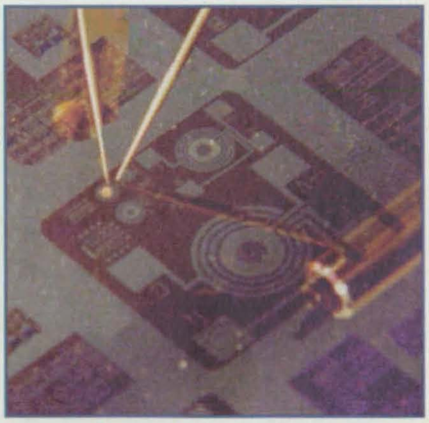
With funding from the U.S. Army and the National Science Foundation, the Rochester team, the largest in the country working on porous silicon, chemically modified the material by partial oxidation, greatly enhancing its thermal and chemical stability while retaining its desirable light-emitting and charge-transport properties. Engineers removed hydrogen atoms from the outer layer of particles and replaced them with a double layer of silicon oxide to produce what is called silicon-rich silicon oxide (SRSO). The modified material can endure the temperatures of 1000 °C typical of the fabrication process, as well as other processing steps such as layer deposition and photoresist etching.



Micrograph of an integrated LED/transistor structure (1), along with the cross-section (2) and equivalent circuit (3). The LED, in the center, has a 400-μm-diameter active light-emitting area. The bipolar transistor surrounds an aluminum contact (crosshatched) to the LED, and has a concentric emitter (E), base (B), and collector (C) terminals. The right half of the cross section shows the LED's polysilicon (poly-Si) local interconnect (LI) and cathode, the transition layer (TL), and the active SRSO layer. The left half shows the vertical (pnp) bipolar driver transistor inside a bulk p-type crystalline silicon (c-Si) substrate collector.

Specifications for the SRSO-based devices at room temperature are as follows: electroluminescence peak from 1.7-2.0 eV; detectable light emission at an applied voltage of ~2 V and a current density of ~10 mA/cm^{-2}; maximum light intensity of ~1 mW/cm^2; highest external power efficiency ~0.1 percent; and modulation bandwidth significantly exceeding 1 MHz. The team says the integrated device's circular design is area-efficient and scalable, provides effective electrical isolation, and demonstrates a truly integrated structure. Devices of various sizes were fabricated, with the active area ranging from 0.005 to 2 mm.

Fauchet's group, which includes Karl Hirschman of RIT's Department of Microelectronic Engineering, whose task it was to do the actual integration of the LED and transistor, as well as research associates Leo Tsybeskov and Sid Duttagupta, now holds the record for the most stable porous silicon LED. They powered the device for 11 straight days before stopping the experiment. Though the LED is also 10,000 times more efficient than the first light-emitting porous silicon developed in 1990, before the material can become really practical, the team says, it must boost efficiency tenfold, to one percent, and increase the bandwidth a hundredfold. Yet, as Fauchet put it, "This is really the first time that porous silicon has lived up to its promise."



Photograph of a chip under test, showing an integrated LED under forward bias, emitting a bright orange photoluminescence.

The development was the subject of a research paper in the November 28, 1996, issue of *Nature*.

Improved Stabilization of Delay in an Optical Fiber

The same optical setup also enables measurement of the delay.

NASA's Jet Propulsion Laboratory, Pasadena, California

An optoelectronic apparatus stabilizes the signal-propagation delay in an optical fiber used to distribute a frequency-standard radio signal as amplitude modulation on an optical carrier signal. The apparatus also serves as a means for measuring the delay. These capabilities will become increasingly important as advanced, highly stable frequency standards come into use: This is because fluctuations in signal-propagation delays introduce phase and frequency fluctuations into the delivered signals, and unless the fluctuations can be suppressed by apparatuses like the present one, it will not be possible to take full advantage of the high quality of the frequency-standard signals.

Figure 1 schematically illustrates the apparatus in the stabilizer configuration. The radio-frequency signal generated by the frequency-standard unit is used to amplitude-modulate the output of an optically isolated laser diode. The laser beam is linearly polarized and is transmitted along a short optical fiber to a polarizing beam splitter, which is oriented, with respect to the polarization of the laser beam, so that the beam can pass through.

Next, the transmitted beam travels along an electrically controlled variable fiber-optic delay line; this is a length of optical fiber coated with a material that has a high coefficient of thermal expansion and is mounted in a controlled-temperature chamber. Thus, the signal-propagation delay can be adjusted by adjusting the temperature in the chamber.

The transmitted beam then propagates along a relatively long optical fiber to its destination, where it encounters a Faraday rotator mirror (a combination of a Faraday rotator and a mirror). In this case, the mirror is half reflective to let half of the beam power go through to a photodetector, which extracts the delivered radio-frequency signal. On the way to the mirror, the Faraday rotator rotates the polarization of the beam by 45°. The half of the beam that is reflected by the mirror passes through the Faraday rotator again, so that its polarization is rotated by another 45°. Thus, the polarization of the light reflected back along the fiber is orthogonal to that of the transmitted beam.

When the reflected light reaches the polarization beam splitter, it does not pass through as did the transmitted beam. Instead, because of its orthogonal polarization, the reflected light is diverted to a right-angle port of the polarizing beam splitter, where a photodetector extracts the round-trip-delayed radio signal. This signal and a replica of the original frequency-standard signal are fed to a phase detector, which puts out a voltage proportional to the cosine of the phase delay caused by propagation along the optical train. This voltage is amplified, filtered, and used as a feedback control (error) signal to adjust the temperature to reduce the error. The feedback loop constantly strives to drive the phase delay toward the zero-cosine, zero-error value of $(4n + 1)\pi/2$ radians (where n is an integer).

In comparison with similar stabilizers developed previously for the same purpose, this one is simpler, yet it performs at least as well and in some cases better. In preliminary tests of this apparatus, the contribution of the stabilized fiber to the instability of the frequency of the delivered radio signal during an observation period of 10^4 seconds ranged from 6×10^{-15} to as low as 9×10^{-17}, and is expected to range as low as about 10^{-18} once the design is optimized.

Figure 2 shows the apparatus in the delay-measuring configuration, which involves the same optical setup but different electronic circuitry. In this configuration, the laser-diode output is mod-

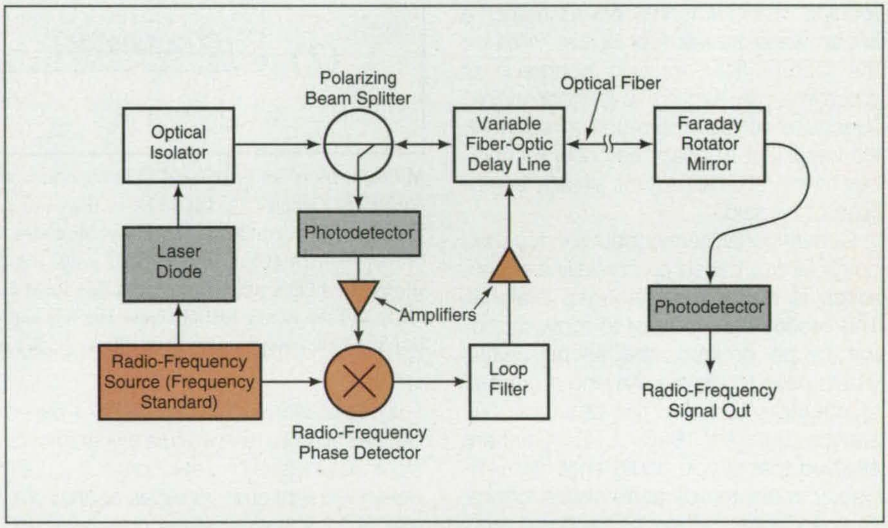


Figure 1. The **Propagation Delay in the Optical Fiber Is Stabilized** by a feedback control loop that adjusts the variable fiber-optic delay line to maintain a constant phase difference at the phase detector.

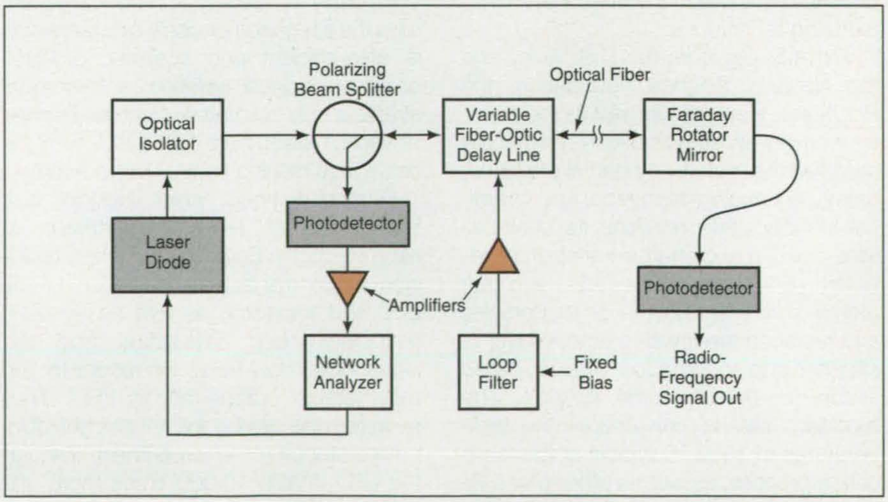


Figure 2. **The Propagation Delay Is Measured** in terms of the variation in phase delay with frequency.

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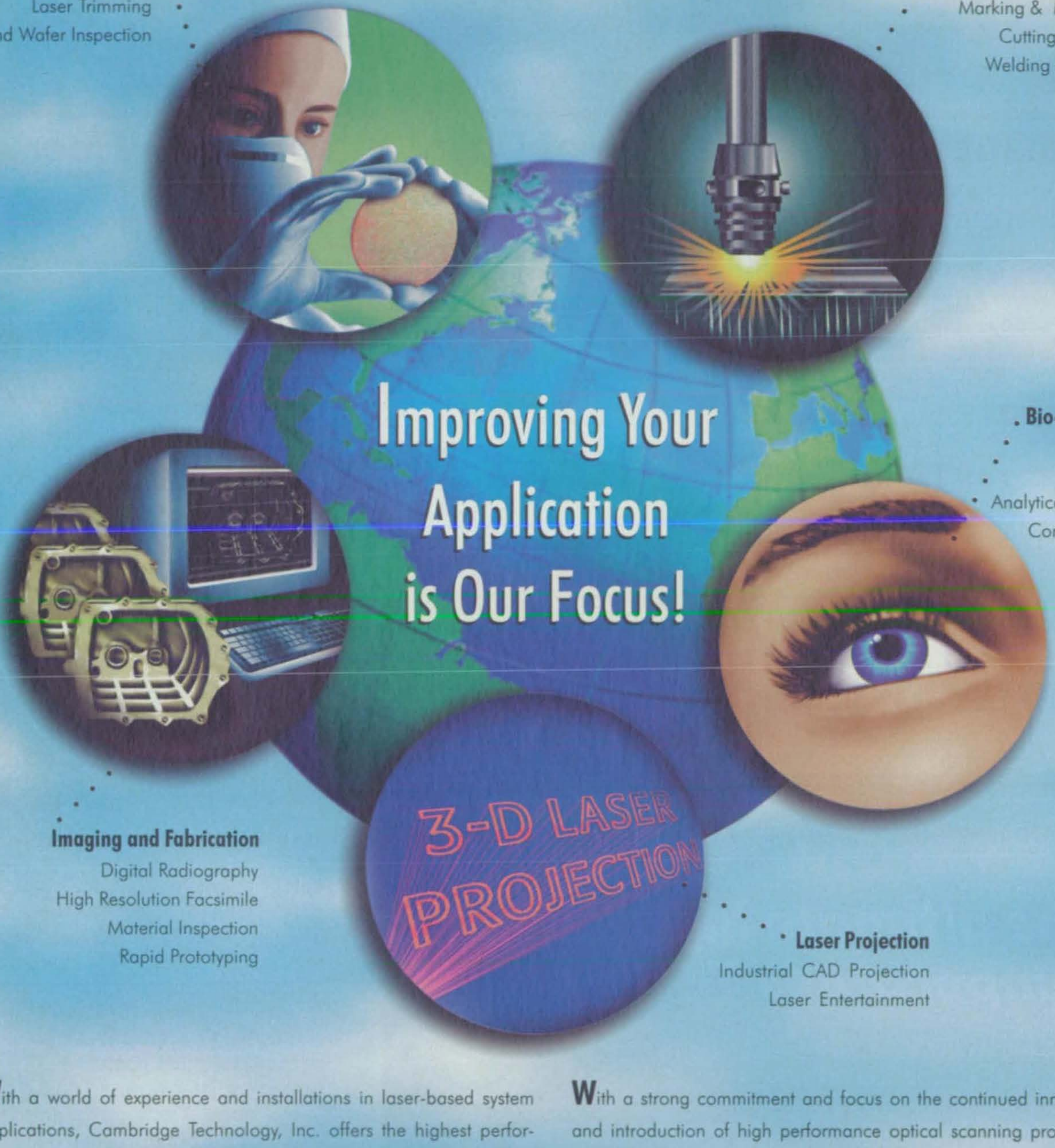

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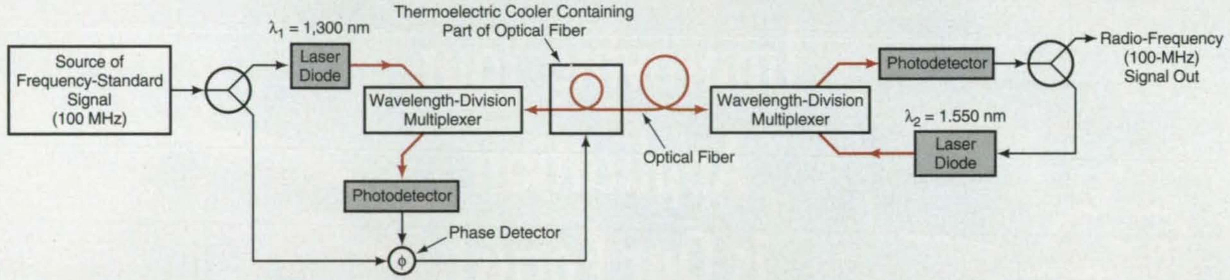
ulated by a swept-frequency radio signal obtained from the output port of a network analyzer, while the round-trip-delayed radio signal is fed to the input port of the network analyzer. The network analyzer then measures the phase delay (φ) as a function of frequency (f), then calculates the time delay (δ) from the equation $\delta = \frac{d\varphi}{d\omega}$. The delay can be measured to within about 10 ps by this technique.

This work was done by George F. Lutes of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 50*** *on the TSP Request Card. NPO-19353*

Alternative for Stabilization of Delay in an Optical Fiber

Transmitted and return signals are discriminated by wavelength instead of polarization.

NASA's Jet Propulsion Laboratory, Pasadena, California

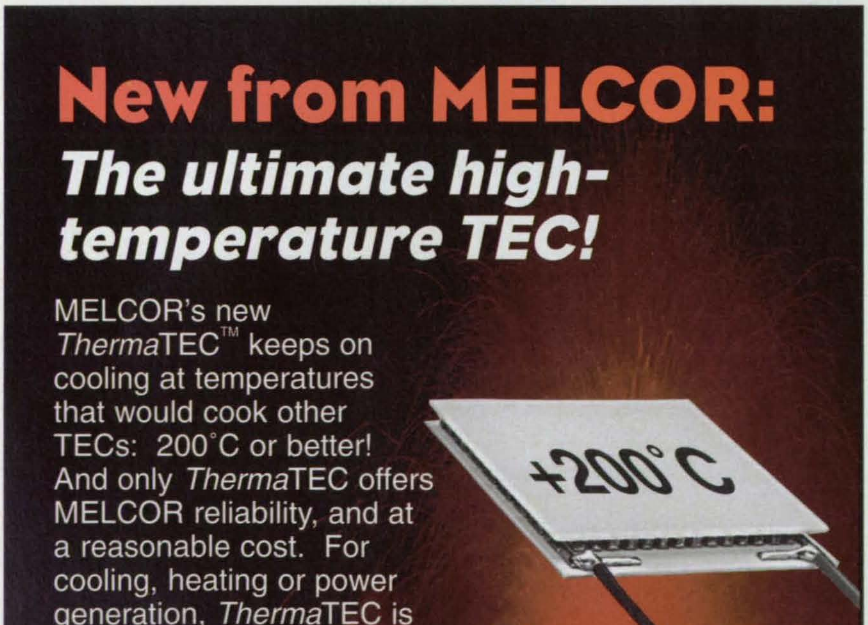


The **Propagation Delay in the Optical Fiber Is Stabilized** against diurnal fluctuations of ambient temperature by a feedback control loop that adjusts the temperature of a part of the optical fiber.

A prototype optoelectronic apparatus helps to stabilize the phase and frequency of a 100-MHz frequency-standard signal delivered to a user station as amplitude modulation of an optical carrier signal propagating in an optical fiber 4.0 km long. The apparatus is intended particularly to suppress phase and frequency fluctuations caused by expansion and contraction of the optical fiber in diurnal heating and cooling cycles, but can also compensate for other fluctuations characterized by times down to about 10 s.

This apparatus is similar to the one described in the preceding article, "Improved Stabilization of Delay in an Optical Fiber" (NPO-19353). In both cases, round-trip phase delay in the optical fiber is measured and used to adjust the temperature of a fiber-optic delay line (part of the optical fiber) in the effort to keep the overall propagation delay as nearly constant as possible. However, the two cases differ in several respects — especially in the techniques used to generate the return signal and to discriminate between the transmitted and return signals.

The present apparatus is illustrated schematically in the figure. The frequency signal is used to amplitude-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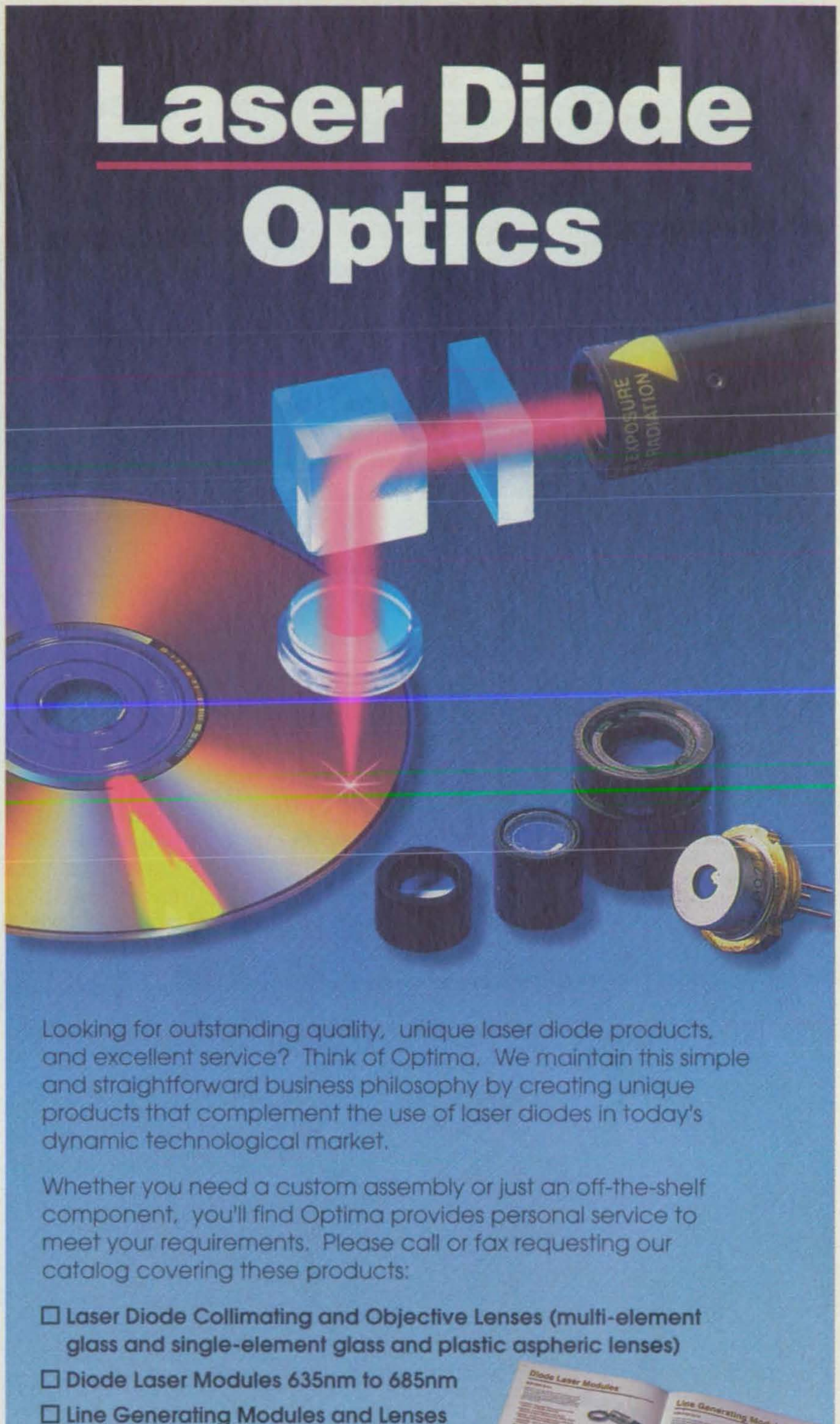
modulate the output of an optically isolated laser diode that emits at a wavelength of λ_1 = 1,300 nm. The laser beam is launched into the optical fiber via a wavelength-division multiplexer. The first 200 m of the fiber is wrapped into a loop that is mounted on the cold plate of a thermoelectric cooler; this constitutes the controlled-temperature fiber-optic delay line. After passing through the loop, the light continues along the remaining 3.8 km of optical fiber to the user station, where it passes through another wavelength-division multiplexer into a photodetector.

This photodetector extracts the delivered radio-frequency signal, which is distributed locally to equipment that requires the precise frequency reference. The radio-frequency signal is also used to amplitude-modulate another laser diode to obtain an optical return signal at a wavelength λ_2 = 1,550 nm. The optical return signal is launched into the optical fiber via the wavelength-division multiplexer.

When it reaches the wavelength-division multiplexer at the other end, the optical return signal is directed to a photodetector, which extracts the radio-frequency return signal. A phase detector measures the difference between the phases of the original frequency-standard signal and the return signal: The output of the phase detector is a phase-difference voltage, which is processed into a control voltage to adjust the temperature of the fiber-optic delay line to drive the phase difference toward zero.

Of course, to the extent to which the phase disturbances at λ_1 differ from those at λ_2 because of wavelength dispersion in the optical fiber, the stabilization can be degraded. In principle, full stabilization could be recovered even in that event, provided that (a) the λ_1 phase disturbance in the delay line is proportional to the λ_2 phase disturbance in the delay line, (b) the λ_1 phase disturbance in the rest of the optical fiber is proportional to the λ_2 phase disturbance in the rest of the optical fiber, and (c) the constant of proportionality is the same in both cases. In a test, the apparatus was found to suppress diurnal-temperature-induced phase fluctuations by a factor of 40.

This work was done by Richard L. Sydnor, Dean R. Johnson, Malcolm D. Calhoun, and George F. Lutes of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information,* ***write in 46*** *on the TSP Request Card. NPO-19075*



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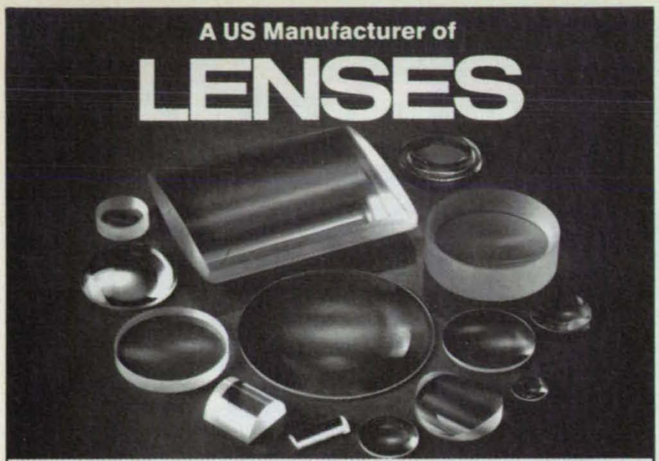

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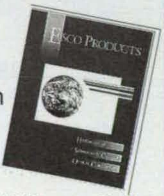

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Electro-Optic Beam-Steering Device

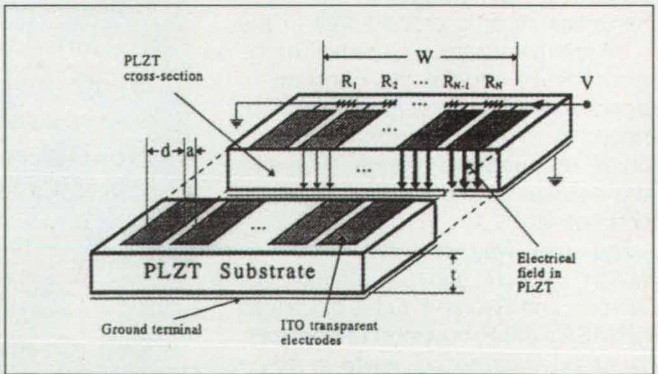
A PLZT ceramic-based electro-optic device combines a resistive network with evaporated electrodes to produce beam steering.

Rome Laboratory, Photonics Center, Griffiss Air Force Base, New York

Optical beam steering has a wide range of applications in optical memory, communications, and free space interconnection. Quadratic lead lanthanum zirconate titanate (PLZT) is a promising material to achieve good beam steering because of its physical stability, fast time response, and high optical transmission. Rome Laboratory researchers demonstrated a PLZT electro-optic beam-steering device that had a 3-mm-X-3-mm working area and deviated the beam 0.04° with an applied voltage of 700 V. A time response of 37.92 ms was measured. Rather than use the transverse electro-optic effect, the team chose the longitudinal electro-optic effect. Transparent electrodes and the voltage-distributing resistors were fabricated on the top surface of the PLZT. On the wafer's bottom surface a semitransparent metal film evaporation provided ground. The figure shows a cross-sectional schematic of the device.

Indium tin oxide (ITO) was deposited for the electrodes, while chromium was used for resistors. The conductive metal film on the bottom of the wafer was a combination of chromium and aluminum. Some transmittance was lost, but the effect sought was not sacrificed. To reduce the electrode resistance, thus shortening the RC constant and providing a faster time response, thin aluminum strips were evaporated onto the center of the electrodes. The electric field in the PLZT wafer varied along the direction perpendicular to the electrodes in a square-root manner. The arrows in the figure depict the field distribution, with the stronger fields represented by the thicker arrows.

The use of the longitudinal field eliminated polarization dependence. The electric field resulting from the inter-electrode voltage difference has little influence on the overall distribution in PLZT. This happens when the PLZT thickness is comparable to the electrode period. In this case, period was 100 microns. The electric field in PLZT results from two components: one is between the electrode and ground, and the other is from the voltage between the electrode and its neighbor electrodes. The first case remained roughly uniform through the PLZT, while the second case existed more near the top surface of the wafer. As a result the index and phase modulation are the effects produced by the electric field com-



Schematic of the **Electro-Optic Beam-Steering Device**.

ponent that lies along the light path. When the electrode spacing is comparably smaller than the thickness of the wafer, the transverse field effect will have a strong influence and may change the properties claimed here.

With proper choice of material, time response, optical transmission and voltage requirements can all be improved. The steering range achieved by this design is relatively small, but it is continuous. Combining this with a blazed grating can result in a large steering range.

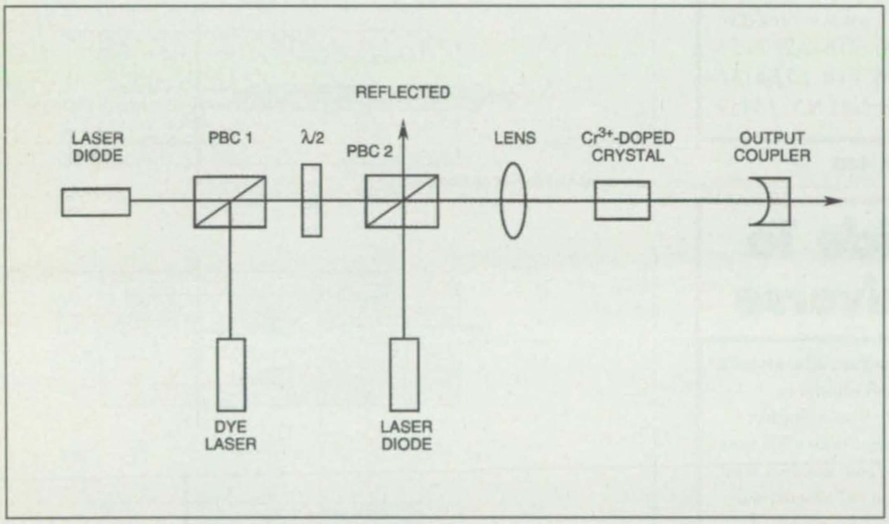
This work was done by Q.W. Song, Xu-Ming Wang, Rebecca Bussjager, and Joseph Osman for the **Rome Laboratory**, *Griffiss Air Force Base, New York, under government contract F30602-94-C-0260. Inquiries concerning commercial use of this technology may be addressed to Rome Laboratory/XP, Griffiss AFB, Rome NY 13441.*

Tunable Lasers Pumped by Visible Laser Diodes

Colquiriite crystals and a novel resonator design combine in a system suitable for medical applications.

Naval Command, Control, and Ocean Surveillance Center, RDT&E Division, San Diego, California

Diode pumping of Nd:YAG and other rare-earth-doped lasers has produced efficient, compact solid-state lasers. However, the fixed frequency output of these materials makes them a poor choice for applications requiring frequency agility. In addition, the narrow absorption linewidths restrict the pump bandwidth to 1-2 nm. But the recent commercial development of high-power red-emitting visible laser diodes has provided the opportunity to demonstrate diode-pumped Cr^{3+} doped vibronic lasers. These solid-state lasers produce tunable emission between 750-1000 nm.



Configuration of **Pump and Resonator Optics** for visible laser-diode-pumped Colquiriite lasers.

A novel laser resonator design enables diode pumping of several Cr^{3+}-doped Colquiriite laser gain elements, including $Cr:LiCaAlF_6$ (Cr:LiCAF), $Cr:LiSrAlF_6$ (Cr:LiSAF), and $Cr:LiSrGaF_6$ (Cr:LiSGAF). These materials are end-pumped by the emission from one or more visible laser diodes. By proper mode matching of both the resonator and pump mode, threshold powers below 10 mW and slope efficiencies in excess of 50% have been obtained.

The Colquiriite laser crystals are among the most efficient Cr-doped vibronic lasers known, and can operate continuous-wave, Q-switched, and mode-locked. In Kerr-lens mode-locked operation, these materials produce pulsewidths of approximately 100 fs. The tunability range of a given crystal can be as high as 200 nm, and doping levels exceeding 50% were demonstrated for Cr:LiSAF. High doping levels enable the use of microscopically thin laser gain elements.

The broadband absorption of these materials makes them ideal for visible laser diode pumping. In addition, the insensitivity of the absorption cross section to pump polarization makes possible efficient polarization combination. The figure shows a typical laser resonator and the associated pump optics. The wavelength range produced by the Colquiriite lasers is particularly useful for medical applications, and second harmonic generation can obtain operation in the blue visible spectrum.

Referring to the figure, two laser diodes are polarization-combined to end-pump the Cr-doped Colquiriite crystal. In addition, a tunable dye laser is used to characterize the laser performance as a function of pump wavelength. With 1 W of diode pump power, over 200 mW of output power was achieved. Narrower-stripe visible laser diodes generated even better results, producing slope efficiencies greater than 50% with low-threshold pump power. High operating efficiency can be obtained without active cooling of the laser diodes, as the broad pump absorption band makes the laser pump efficiency insensitive to pump wavelength.

The coherence properties and power scaling of visible laser diodes are expected to improve with time. This will allow scaling the excellent results obtained with the narrow-stripe diodes to higher output power. In addition, commercial availability of the Colquiriite laser crystals is rapidly expanding, and diode-pumped output powers exceeding 0.5 W can now be obtained.

This work was done by Dr. Richard Scheps of the **Naval Command, Control, and Ocean Surveillance Center**, *Research, Development, Test, and Evaluation Division. Inquiries concerning rights for the commercial use of this invention should be addressed to Commanding Officer, Attn: Technology Transfer Liaison, NCCOSC RDTE DIV 0143, 53560 Hull St., San Diego, CA 92152-5001; (619) 553-2101.*

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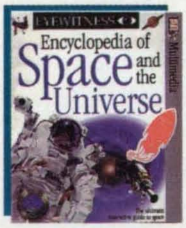

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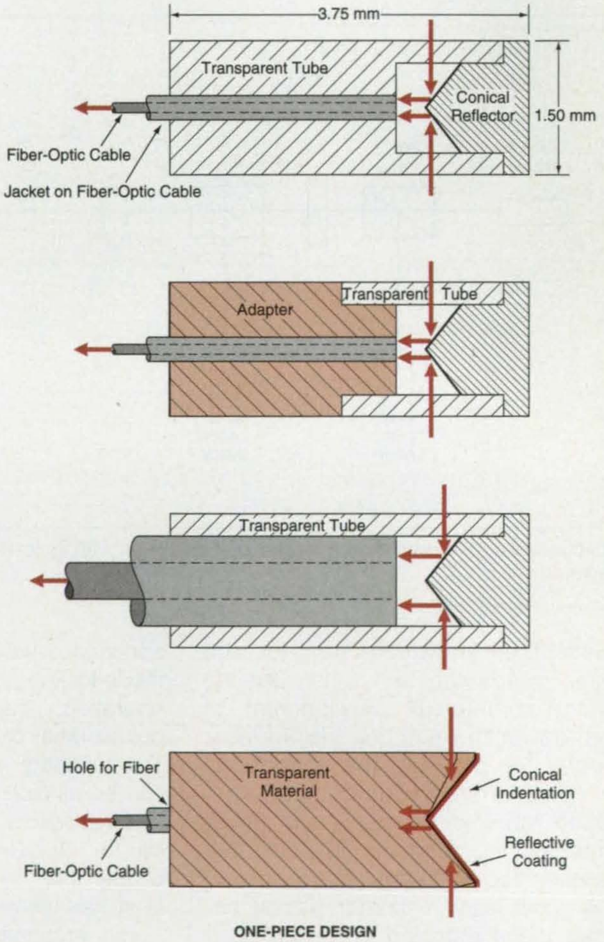
Tip Modules for Fiber-Optic Endoscopes With Radial Views

The tip modules would be simple, inexpensive, and self-aligning.

NASA's Jet Propulsion Laboratory, Pasadena, California

Self-aligning optical modules have been proposed for installation on tips of optical fibers or fiber-optic cables of endoscopes to provide radial views; that is, views perpendicular to the longitudinal axes of the cables or fibers. In the original application that gave rise to the proposal, there was a need for such a tip to provide radial views to an infrared-transmissive optical fiber for endoscopic measurements of temperature.

A module according to this concept would include a conical reflector in a transparent tube. In the original application, the



A Simple Module Would Fit on the End of an optical fiber or cable of optical fibers. The dimensions shown are exemplary only.

tube would have to be made of a material transparent to infrared radiation. The inner diameter of the tube would be chosen to obtain a sliding (but not excessively loose) fit with the tip of the optical fiber or cable or with a ferrule or other adapter attached to that tip. Radiation striking the cone radially would be reflected axially into the fiber. Although the figure shows a flat conical reflector, other designs could include curved surfaces. The bottom of the figure shows a one-piece design for ease of manufacturing. Transparent material is molded or shaped into a cylinder with a hole for the fiber at one end, and a conical indentation at the opposite end. The outside of the conical surface is coated with a reflective material. The total internal reflection effect may conceivably be used, under certain conditions, for certain angles of reflection, instead of the reflective coating.

The fit would help to ensure optical alignment. In addition, the adapter could incorporate a shoulder stop to ensure an axial distance between the fiber-optic tip and the conical reflector and thereby reduce the angular optical error caused by slight eccentricity in the alignment of mating parts.

The modules could be mass-produced inexpensively. The conical reflectors could be made of metal (e.g., aluminum) or of molded plastic coated with metal. The tubes could be made of molded plastic. It might be possible to combine the tube and reflector into a single molded part. If the tube had to be ground or machined from a special material (e.g., sapphire), then the portions of its inner and outer surfaces through which radiation would pass should be polished.

This work was done by Hiroshi Kadogawa, Michael Eastwood, Gregory Bearman, and Timothy Krabach of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 91*** *on the TSP Request Card.*

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:

William T. Callaghan, Manager
Technology Commercialization
JPL-301-350
4800 Oak Grove Drive
Pasadena, CA 91109

Refer to NPO-19466, volume and number of this NASA Tech Briefs *issue, and the page number.*

Fixture for Stripping Coatings From Jacketed Optical Fibers

The fixture holds a fiber precisely for chemical stripping.

Goddard Space Flight Center, Greenbelt, Maryland

A fixture holds a jacketed glass optical fiber in a chemical solution for stripping of its coating layer in preparation for mounting in a connector. Unlike mechanical stripping, chemical stripping does not nick or scratch the glass fiber. The fixture improves on simply immersing the end of a fiber in a chemical stripping solution by ensuring that a precise length of coating, with a well-defined edge, remains.

The fixture (see figure) consists of a handle and a fixture body, both made of polytetrafluoroethylene or other suitable material that is chemically inert in the stripping solution. A jacketed optical fiber, with its inner and outer jackets trimmed away from its end, is threaded through the disassembled handle and fixture body so that the coated fiber protrudes from the fixture body and the inner jacket abuts a shoulder stop in the body. The handle is then screwed onto the body.

The tip of the fixture body and the protruding end of the fiber are immersed in the stripping solution up to a notch that encircles the tip of the fixture body. After about 90 seconds, the coating softens. The fixture and fiber are then withdrawn from the solution and the body is unscrewed from the handle, wiping away the coating from the fiber. Optionally, the coating can be wiped off with a soft cloth before unscrewing the fixture body.

The length, *L*, of the remaining coating protruding from the outer end of the inner jacket is determined by the dimensions of the fixture body; in particular by the length of the axial hole from the shoulder stop to the tip. Several fixture bodies, fabricated with different axial-hole lengths, are available so that an appropriate length for mounting can be selected. The value of *L* on the stripped fiber is generally accurate to within

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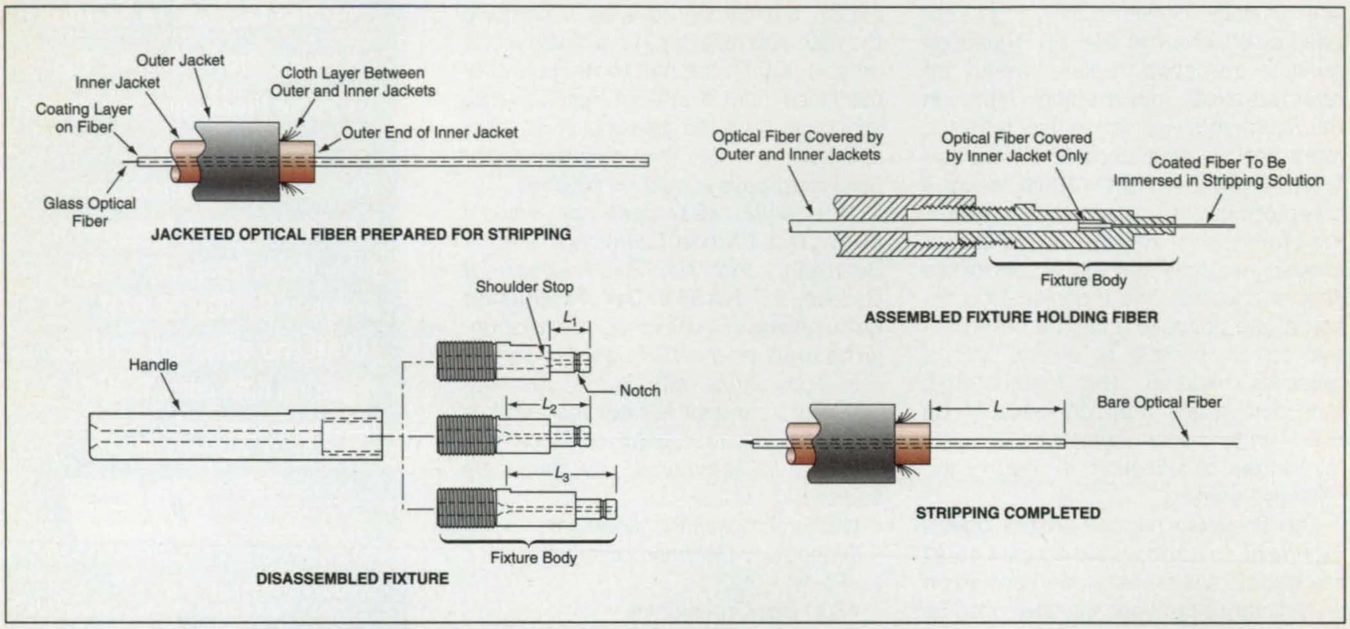
0.010 in. (0.25 mm).

This work was done by John Kolasinski and Alexander Coleman of **Goddard Space Flight Center.** *For further information,* ***write in 31*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Goddard Space Flight Center; (301) 286-7351. Refer to GSC-13644.



The **Stripping Fixture Holds a Jacketed Optical Fiber** in such a way that a controlled length can be immersed in a stripping solution. A length, *L*, of coating remains on the fiber.

LITERATURE SPOTLIGHT

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Two new coatings from Acton Research, Acton, MA, are designed to optimize minimum reflectance and maximum transmittance over specific broad bands of the ultraviolet spectrum. At normal incidence on a coated fused silica substrate, average reflectance for the range 193-248 nm is 0.4-0.8 percent, and for the 248-355-nm range 0.2-0.6 percent. Acton recommends these electron-beam-deposited dielectric coatings for increasing the transmittance properties of lenses and reducing the second-surface reflections of beamsplitters.

For More Information Write In No. 800

Tunable 633-nm Diode Laser

New Focus Inc., Santa Clara, CA, has added a 633-nm laser to its family of external-cavity tunable diode lasers, and announced a $5000 price reduction on the complete line. The company recommends the 633-nm unit as a replacement for single-line HeNe lasers, saying it offers comparable linewidth performance (300 kHz at 50 ms) but better tunability of more than 10 nm and modulation capability of more than 100 MHz. New Focus says primary applications are spectroscopy, frequency references, and interferometry.

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Standard and Custom Parabolic Mirrors

A family of standard and custom parabolic mirrors comes from OptoSigma Corp., Santa Ana, CA. Available in off-axis and on-axis configurations up to 16 in. in diameter, these paraboloids are hand-polished from large blanks of fine-annealed low-expansion glass to precise focal lengths. Surface accuracy is 1/10 wave. Coatings include protected aluminum, enhanced silver, gold, or broadband dielectric thin films. Other aspheric mirrors available include ellipsoids, toroids, and hyperboloids.

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Laser Diode with Controllable Intensity

The Beta EC laser diode from Vector Technology, Abertillery, Gwent, U.K., permits the user total electronic control of beam power. Based on Vector's Beta CW module, it has an input providing linear beam intensity control from zero to the factory-set maximum. The company says control is best achieved using a current source such as a simple transistor and resistor, or a digital-to-analog converter, or with less linearity using a potentiometer. It is available with all the options offered for Vector's Beta CW, TX, and AL series laser diodes in wavelength, power, and lenses.

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Optical Analysis Based on ACIS®

Lambda Research Corp., Littleton, MA, introduces TracePro™, which it calls the first optical analysis program to have the industry-standard solid modeling engine ACIS® at its core. TracePro uses the Monte Carlo ray-tracing method to compute optical flux as it propagates through a model. It can analyze absorption, specular reflection and refraction, scattering and aperture diffraction of light on any surface. Measured data can be viewed as contour maps or as ray histories in tabular form. New users can purchase the base module for $4000.

For More Information Write In No. 801

Laser Coordinate Measuring Machine

SMX Corp., Kennett Square, PA, says its new laser-based Tracker4000 coordinate measuring machine was developed to provide extremely precise 3-D measurements of large-scale objects. Measurement range is 1 to 100 meters in size, with an accuracy of 25 µm (0.001 in.) at 5 m (17 ft.). With its angular encoders it can measure X, Y, and Z positions in any user-defined coordinate system, taking 1000 readings per second. SMX says the Tracker4000 can replace optical tooling, large CMMs, and computerized theodolite or photogrammetry systems.

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High-Capacity Oil Mist Eliminator

The Maxi-Mist 10 oil mist eliminator for large vacuum pumps from MV Products, North Billerica, MA, is a high-capacity exhaust trap that employs a parallel bank of five pleated microfiberglass coalescing filter elements, each with a 0.1-micron pore size. Constructed entirely of stainless steel, and equipped with a port for draining or recirculating pump fluids, the device measures 10 in. (D) x 13.5 in. (H). List price for the Maxi-Mist 10 is $1450.

For More Information Write In No. 808

Multichannel Tunable Laser Source

E-TEK Dynamics Inc., San Jose, CA, has developed a mechanically tunable high-power external-cavity laser source. Called the MTLS, it delivers more than +10 dBm optical output power at either 1530 nm (tuning range ± 45 nm) or 1300 nm (± 25 nm). Linewidth is < 1 MHz. It can be remote-controlled through IEEE-488 or RS-232 ports, or with a front-panel touch screen. The mainframe chassis holds up to four compact plug-in modules, each with two-layer temperature control, one for laser and the other for cavity temperature stabilization.

For More Information Write In No. 810

MAESTRO Applications for FO Test System

As part of its IQ-200 fiber optic test system, EXFO E.O. Engineering, Vanier, PQ, Canada, developed *MAESTRO* applications in Visual Basic™. These include component insertion and return loss, multiple DUT testing, and source power measurements. Test jumper qualification applications and others are under development. Insertion and return loss can be tested on splitters from 1x2 up to 1x16 for 1310/1550-nm wavelengths using the IQ-2100 dual source, IQ-3200 ORL meter, and IQ-1200 4-channel power meter.

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High-Speed Imaging Camera System

Adaptive Optics Associates (AOA) Inc., Cambridge, MA, introduces the Desktop KineView™, a complete high-speed CCD video system that includes a 1000-frame-per-second digital video camera, a Pentium™ computer with 2048-frame capacity, interface board, external event trigger and frame synchronization, strobe trigger output, and software. AOA suggests the system for factory-floor problems, lab motion studies, failure analysis, beam profile and wavefront measurements, and automotive crash and engine testing, among other uses.

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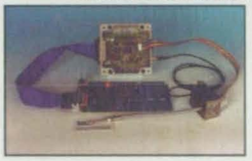


Monolithic Miniature Spectrometer

Hellma Cells, Forest Hills, NY, distributes the Zeiss line of monolithic miniature spectrometers with a variety of electronics. Measuring 65 x 50 x 40 mm, the MMS1 module consists of an input fiber optic with cross-section converter, a solid glass lens with grating, and a laser diode array. It covers wavelengths from 300-1500 nm; other MMS modules cover from 190 nm up. The Tec5 14-bit electronic interface offers extended dynamic range, integration times from 4 ms to 6.5 s, and a multiplexer option. Demonstration software with source code is provided for a variety of applications.

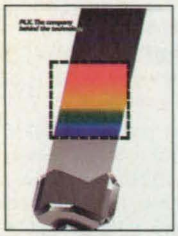
For More Information Write In No. 806

Laser Spectroscopy Raman Probe

The Manhattan™ fiber optic Raman probe from Vision-ex, Warner Robins, GA, utilizes optical fibers for remote analysis in hostile environments. Designed for radionuclide waste and environmental contaminant processing sites, it is outfitted with Rad-Lok™ radiation-hardened fiber optic packaging, providing chemical, temperature, and hermetic isolation. The patent-pending probe employs Gaser™ light management-technology, using selective instrument sensitivity for more effective laser spectroscopy, the company says.

For More Information Write In No. 811

NEW LITERATURE



Hollow Monolithic Optical Structures

PLX Inc., Deer Park, NY, has released a full-color capabilities brochure that describes its hollow retroreflector technology. The company says its retroreflective devices provide high-quality return wavefronts in all wavelengths and under severe environmental conditions. Highlighting engineering, manufacturing, and testing capabilities, the booklet also features examples of devices such as lateral transfer hollow retroreflectors and periscopes, hollow retroreflector arrays, and hollow roof mirrors for a variety of military, aerospace, industrial, and scientific applications.

For More Information Write In No. 813

Fiber Optic Sensors for Metrology, Process Control

Just issued by Photonetics Inc., Wakefield, MA, is a 24-page catalog of fiber optic sensing probes for metrology and process control. The "Fiber Optic Probe Guide" has descriptions and specifications on probes for temperature, pressure, refractive index, current, chemical concentration, opacity, volumetric void fraction, rotation speed, and on-off switching measurement. All probes in the guide interface with the company's MetriCor 2000, which conditions the signal for measurement.

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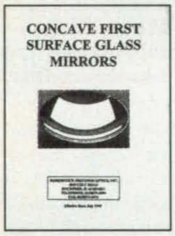

Precision Optical Components

Rodenstock Precision Optics Inc., Rockford, IL, has issued four booklets describing the company's precision optical components offered as standard items. These include aspheric glass condenser lenses, plano-convex, biconvex, and convex-concave glass singlet lenses, concave first-surface mirrors, and heat-absorbing filters of B270, F2, Duran, KG1 and KG3 glass materials. The booklets also describe the custom-designed and manufactured optical components Rodenstock supplies to satisfy specific applications.

For More Information Write In No. 817

Selection Guide to Pressure Test Products

The pressure measurement product selection guide from MKS Instruments, Andover, MA, has complete specifications for the company's 600 series sensor line, including absolute, differential, and bakeable versions, the Type 670 microprocessor-based electronics/display units, and the three-channel temperature controllers and multiplexers. The 600 Series Baratron® pressure measurement systems combine advanced capacitance diaphragm sensor technology and solid-state electronics for use on production tools and in research laboratories.

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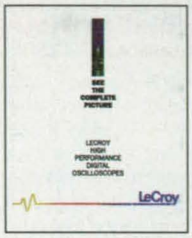

High-Performance Digital Oscilloscopes

A 12-page technical brochure from LeCroy Corp., Chestnut Ridge, NY, is available to design and test engineers seeking information on high-performance digital oscilloscopes. The booklet has examples of how the company's products assist the engineer in capturing, viewing, and diagnosing electronic signals. It also contains technical specifications, feature descriptions, and ordering information on LeCroy's 9384, 9370, and 9350 series instruments.

For More Information Write In No. 814

Close-Tolerance Machining of Materials

A capabilities brochure from Hardric Laboratories, Waltham, MA, describes the company's expertise in machining materials such as aluminum, beryllium, tungsten, titanium, stainless steel, metal matrix composites, and ceramics. Hardric says its Metal Optics Center is the world leader in providing polished low-scatter beryllium IR laser mirrors and coated low-scatter beryllium mirrors for the IR, VIS, and UV. Hardric also offers single-point diamond turning of optics and other precision components.

For More Information Write In No. 816

Fiber Optic Immersion Probes

A 12-page catalog from Hellma, Forest Hills, NY, details its line of fiber optic immersion probe cells for remote spectrophotometric measurements of liquids. Constructed from low-OH quartz for transmission of beams from 220-2300 nm, the probes are available in fixed path lengths from 1 to 20 mm. A variety of probes cover usage with aggressive chemical liquids and in temperature extremes. Fluorescence/luminescence versions are also available. Stainless steel or PEEK plastic sleeves can be added for more protection. Also available is a fiber optic interface for use in standard instruments.

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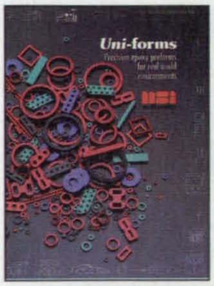

Epoxy Preform Product Line

Multi-Seals Inc., Manchester, CT, offers a 4-page brochure describing its Uniforms™ epoxy preform product line. It contains an overview of standard and custom preform applications, comparisons of preform with traditional liquid dispensing systems, product specifications, and an introduction to the automatic, semiautomatic, and manual loading system options available.

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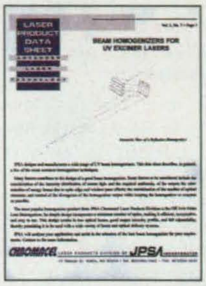

UV Laser Beam Homogenizer

A literature release from JPSA, Hollis, NH, calls its OXH UV laser beam homogenizer the most cost-effective and versatile beam homogenizer on the market. Designed for industrial excimer laser applications requiring high-efficiency beam utilization and uniform exposures, the OXH provides long working distances and a substantial depth of field while maintaining ±5 to ±10 percent beam uniformity. The device is part of JPSA's Chromacel line of laser products.

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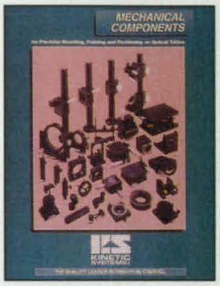

Broad Line of Mechanical Components

A newly revised 56-page catalog from Kinetic Systems, Boston, MA, has details on the company's line of positioners, mounts, holders, adapters, and microholes designed to be used with Kinetic's optical tables and others as well. An 8-page supplement also supplies details on Kinetic's line of optical table and vibration isolation components.

For More Information Write In No. 822

Epoxies and Polymers for High-Tech Applications

A brochure from Epoxy Technology, Billerica, MA, explains how the company's epoxies and polymers are optimized for bonding, coating, encapsulating, and interconnecting in optoelectronic assemblies, fiber optic cable assembly, semiconductor packaging, hybrid microelectronics, and many other applications. The publication tells how the electrical, thermal, and physical properties of the materials can be selected and modified to meet specific user requirements.

For More Information Write In No. 823

Digital Oscilloscopes and Other Test Instruments

The 204-page 1997 catalog from LeCroy, Chestnut Ridge, NY, has complete technical information on their digital storage oscilloscopes (DSO) and other test and measurement product lines. It also contains an overview of new products for the year and 90 pages of technical tutorials and application notes. New products include six DSOs from the high-performance color LC534 and LC334 lines and the 9384AL 1-gigahertz-bandwidth digital scope. Application notes focus on troubleshooting intermittent circuit faults, making more accurate jitter measurements, DSO applications in high-speed digital circuits, and many other topics.

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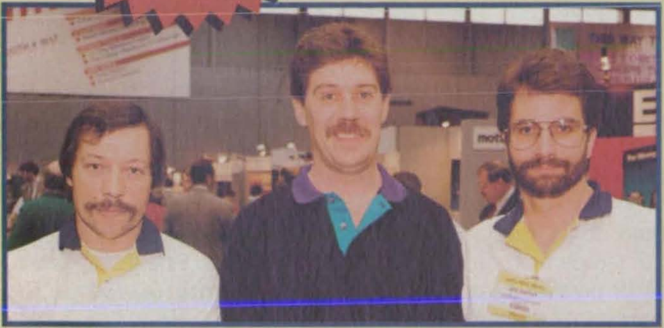

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For More Information Write In No. 665

Growing Prostate-Cancer Cells in Three-Dimensional Clusters

An artificial growth process will help fill gaps in cancer research.

Lyndon B. Johnson Space Center, Houston, Texas

A process produces relatively large three-dimensional clusters of human prostate-cancer cells for research. These cell cultures are more accurate as models for *in vivo* studies and as sources of seed cells for *in vivo* studies than can be obtained in older cell-culturing processes. This process is effected in a horizontal rotating bioreactor like that described in the article, "Simplified Bioreactor for Growing Mammalian Cells" (MSC-22060), *NASA Tech Briefs*, Vol. 19, No. 12 (December, 1995), page 24.

Although prostate cancer has been well researched and is one of the better understood carcinomas, there are substantial gaps in knowledge because of the lack of faithful three-dimensional *in vitro* models of *in vivo* cells. This process may provide the aggregates of cells needed to fill many of the gaps.

In a demonstration of one version of the process, normal human fibroblast cells were injected into a culture medium in a 110-milliliter bioreactor vessel at a concentration of 400,000 cells per milliliter. Microcarrier beads were added at a concentration of 5 milligrams per liter. The reactor was rotated at 25 revolutions per minute at a temperature of 37 °C and humidity of 98 percent in an atmosphere that contained 5 percent CO_2. Within 2 days, cells had grown into visible aggregates. Once the aggregates had become confluent, covering entire beads, human prostate cells were added at a concentration of 200,000 cells per milliliter. When the resulting aggregates of normal and malignant cells reached a diameter of 4 mm, they were removed from the reactor for use. The demonstration of another version of the process was similar except that a standard mixture of prostate-cancer cells was injected at the beginning, and there were no additional injections.

This work was done by Glenn F. Spaulding of **Johnson Space Center** *and Tacey L. Prewett and Thomas J. Goodwin of Krug Life Sciences. For further information,* ***write in 150*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center; (713) 483-4871. Refer to MSC-22119.

Growing Three-Dimensional Corneal Tissue in a Bioreactor

This method could help overcome the shortage of donated corneal tissue.

Lyndon B. Johnson Space Center, Houston, Texas

Spheroids of corneal tissue about 5 mm in diameter have been grown in a bioreactor from an *in vitro* culture of primary rabbit corneal cells to illustrate the production of optic cells from aggregates and tissue. In comparison with corneal tissues previously grown *in vitro* by other techniques, this tissue approximates intact corneal tissue more closely in both size and structure. This novel three-dimensional tissue can be used to model cell structures and functions in normal and abnormal corneas. Efforts continue to refine the present *in vitro* method into one for producing human corneal tissue to overcome the chronic shortage of donors for corneal transplants: The method would be used to prepare corneal tissues, either from *in vitro* cultures of a patient's own cells or from a well-defined culture from another human donor known to be healthy.

As explained in several articles in prior issues of *NASA Tech Briefs*, generally cylindrical horizontal rotating bioreactors have been developed to provide nutrient-solution environments conducive to the growth of delicate animal cells, with gentle, low-shear flow conditions that keep the cells in suspension without damaging them. The horizontal rotating bioreactor used in this method, denoted by the acronym "HARV," was described in "High-Aspect-Ratio Rotating Cell-Culture Vessel" (MSC-21662), *NASA Tech Briefs*, Vol. 16, No. 5 (May, 1992), page 150.

To start a culture, the nutrient medium in the bioreactor is inoculated with a mixture of primary corneal cells, including endothelial cells, epithelial cells, and keratinocytes. Because these cells depend on attachment, microcarrier beads are also introduced to provide support. In the initial experiments, insoluble beads were used; alternatively, one could use microcarriers that dissolve as the tissue grows, leaving only the tissue. Another alternative would be to introduce other cells so that the cells of all types present could use each other for support.

In the culture, the cells grow, multiply, migrate into clusters, and produce an intracellular matrix via the functional interrelationship of cell-to-cell contact. The cells differentiate and grow along boundaries characteristic of normal functional tissue. The tissue thus formed has a layered structure (see figure) similar to that of an intact cornea.

A **Tissue Specimen Was Stained** to reveal chondroitin-6-sulfate, which is a constituent of the intracellular matrix. The cells have bridged between microcarrier beads and organized themselves into approximately parallel layers. The magnification in this photograph is about 200.

This work was done by Glen F. Spaulding, Thomas J. Goodwin, and Laurie Aten of **Johnson Space Center**, *Tacey Prewett and Wendy S. Fitzgerald of Krug Life Sciences, and Kim O'Connor, Delmar Caldwell, and Karen M. Francis of Tulane University. For further information,* ***write in 59*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Johnson Space Center; (713) 483-4871. Refer to MSC-22368.

Treating Wastewater With Phototrophic Bacteria and Sunlight

Marshall Space Flight Center, Alabama

A proposed wastewater-treatment system would use phototrophic bacteria in the presence of sunlight to convert organic wastes into harmless biomass plus hydrogen, methane, and carbon dioxide gases. The biomass could be used to fertilize plants. Development efforts thus far have included experiments and the identification of a number of phototrophic and heterotrophic microorganisms, specific ones of which can be selected to degrade specific compounds that are otherwise considered biorecalcitrant. The experiments showed that improved phototrophic treatment cells containing such organisms are capable of extended operation with only intermittent supplementation with microorganisms or nutrients. When operated in conjunction with filters and/or centrifuges for physical separation, the cells were found capable of reducing key wastewater parameters such as biochemical oxygen demand and chemical oxygen demand by 95 percent. The proposed system should be applicable, in places with abundant sunlight, to treatment of sewage, of some specific food-processing and industrial-waste streams, and of some specific hazardous-waste streams.

This work was done by Dennis Ray Schneider of Micro-Bac International, Inc., for **Marshall Space Flight Center**. *For further information,* ***write in 80*** *on the TSP Request Card.*
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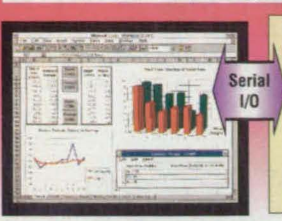

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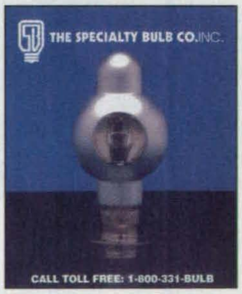

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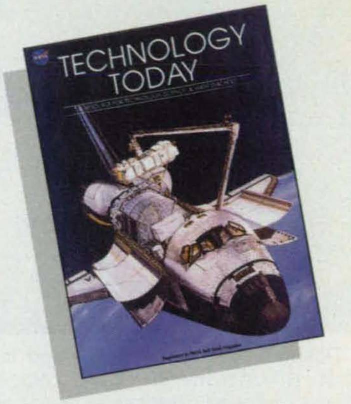

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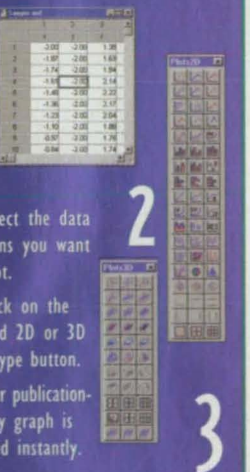

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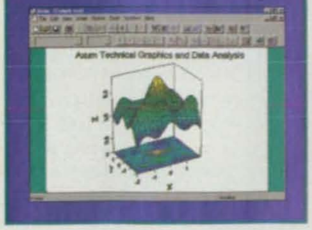

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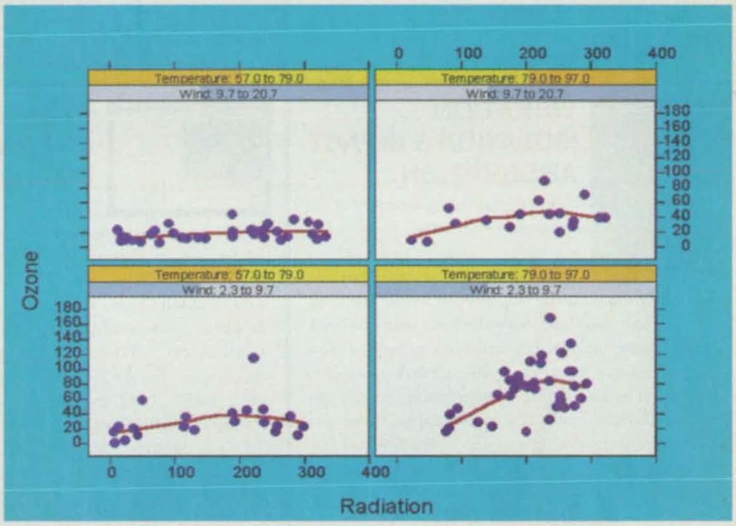

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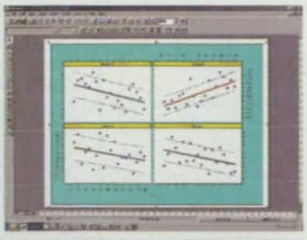

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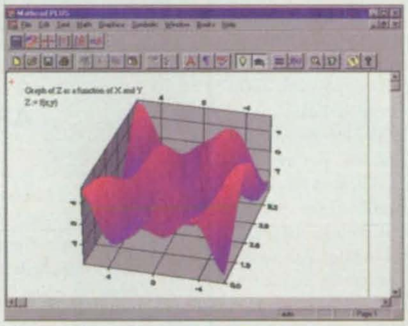

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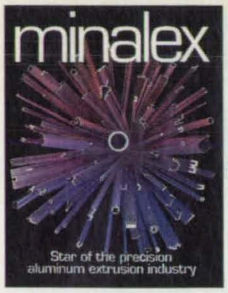

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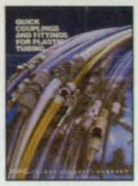

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Sorbothane, Inc.

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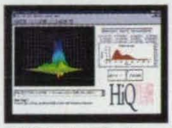

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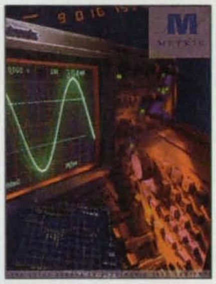

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NESLAB Instruments Inc.

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ABB K-Flow

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IOtech, Inc.

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Carborundum Corporation, Boron Nitride Division, offers an eight-page, full-color brochure detailing Combat® Boron Nitride, available in solid, powder, coating, and aerosol spray forms for a variety of design applications. Four-page insert provides technical data. Carborundum Corporation, Boron Nitride Division, 168 Creekside Drive, Amherst, NY 14228; Tel: 716-691-2052; Fax: 716-691-2090.

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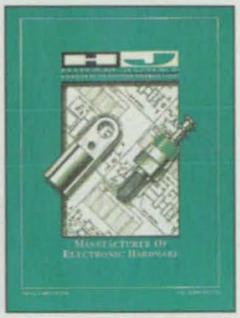

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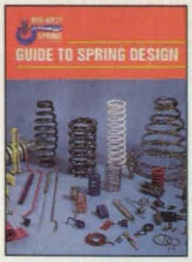

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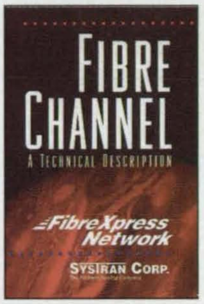

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Integrated Systems Inc.

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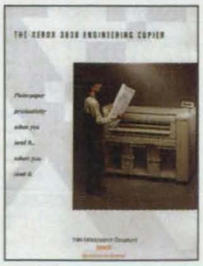

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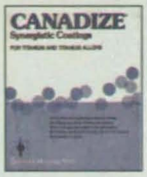

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APPLICATIONS GUIDE FOR RETICULATED POLYURETHANE FOAM

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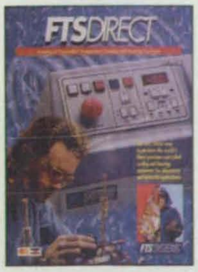

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For More Information Write In No. 379

MOTION CONTROL

Oregon Micro Systems' new motion control product guide – a full line of multi-axis controllers with up to 8 axes on a single board. Thanks to exclusive patented technology, OMS motion controllers have higher reliability and lower costs. Shipment is from stock for immediate delivery. Oregon Micro Systems Inc., 1800 NW 169th Place, Ste. C100, Beaverton, OR 97006; Tel: 503-629-8081; Fax: 503-629-0688.

Oregon Micro Systems Inc.

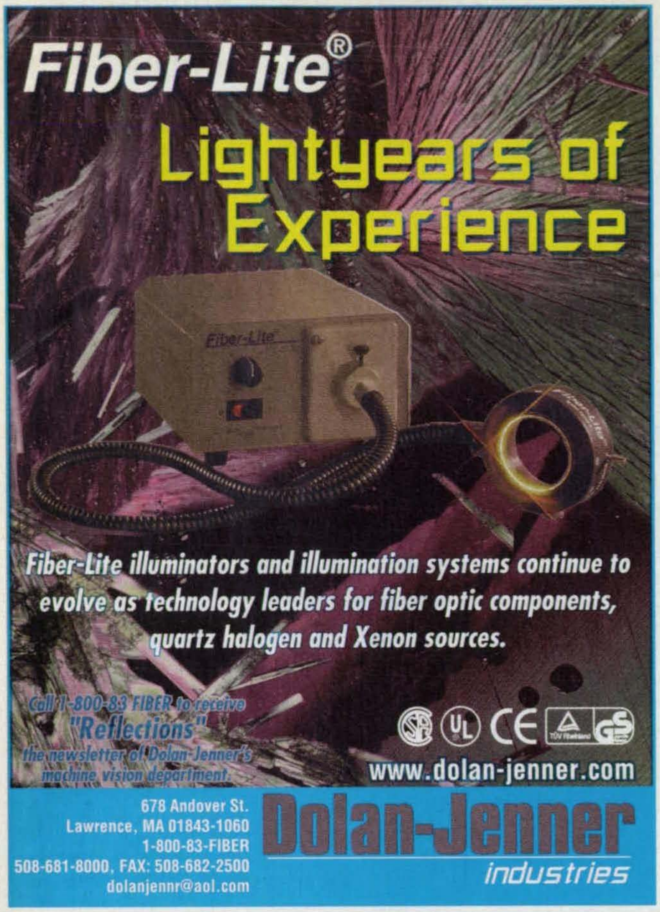
For More Information Write In No. 380

BORESCOPIC VIDEO SYSTEM

The MCV-8000 borescopic video system couples any Machida borescope to a miniature, high-quality color camera to create the clearest images for review on a monitor screen. Designed to be portable, the MCV-8000 is a quick set-up unit that is fully protected in a shock-mounted, shippable carrying case. The 1/2" VHS record/playback unit with microphone allows inspections to be recorded easily with narration. The MCV-8000 borescope video system is the professional choice for high-resolution video inspections. Machida, Inc., 40 Ramland Road S., Orangeburg, NY 10962; Tel: 800-431-5420.

Machida, Inc.

For More Information Write In No. 381



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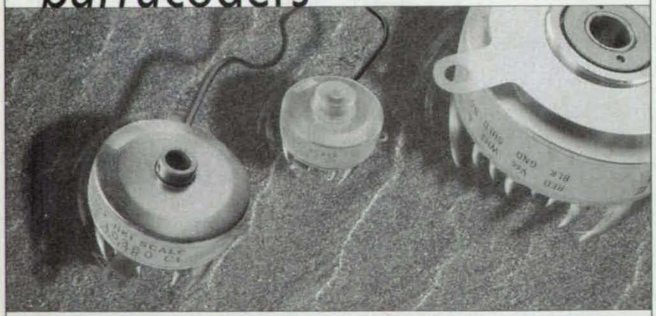

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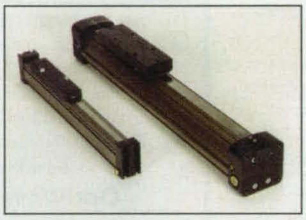
For More Information Write In No. 421

New on the Market

Teknor Industrial Computers, Boca Raton, FL, has introduced the TEK-FIELD-OEM industrial **handheld computer**, which features a Pentium processor, removable media, PCMCIA cards, flash memory, parallel/serial/IR links, docking station interface, and voice command option. The unit has a 6.4" color display with touchscreen and external connectors for access to CD-ROM drives or PCI bus transfer.

For More Information Write In No. 710



The Series 170 **rodless cylinders** from Rexroth Corp., Pneumatics Div., Lexington, KY, are available in bore sizes of 16, 25, 32, 40, 50, 63, and 80 mm. Features include a choice of NPT ports and UNC mounting threads, or metric ports and mounting threads; adjustable cushions and urethane bumpers; anodized aluminum barrel; and magnetic piston assembly. Dual ports allow air line connection; nylon bearings protect sliding surfaces.

For More Information Write In No. 711

Silicon Graphics, Mountain View, CA, has introduced the Octane™ **desktop workstation**, which features a one-to-one crossbar switch that allows different computer subsystems to communicate directly, without interference. The system provides one or two MIPS® R10000™ processors that operate simultaneously or independently. It is available in three graphics configurations with 64 Mb to 2 Gb of memory, and with 10 Mb/100 Mb Ethernet and two Ultra-SCSI buses.

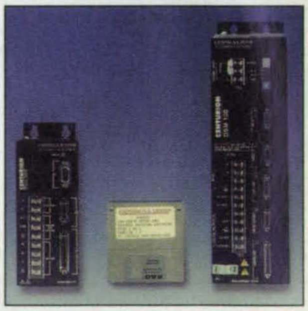
For More Information Write In No. 712

The Powerpac™ **hybrid stepper motors** from Pacific Scientific Automation Technology Group, Motor Products Div., Rockford, IL, are available in NEMA 34 and 42 frames. The N Series features holding torques to 272.8 lb-in; the K Series holding torques are enhanced to 356 lb-in. Both models incorporate a large-diameter rotor and rotor/stator design. Termination and encoder options are available.

For More Information Write In No. 713

The ITS Power Manager **electric motor control system** from Mellin Industries, Fort Lauderdale, FL, helps manage the power consumed by electric motors. It provides early detection of conditions, including power source faults such as over- or under-voltage and electromechanical problems, and shuts down the motor if problems are detected.

For More Information Write In No. 715



Giddings & Lewis, Fond du Lac, WI, has introduced the DSM and Micro DSM Centurion™ **servo systems**, and the YSM-Series and NSM-Series servo motors. The DSM digital amplifiers feature power supplies of 0.5, 1.0, and 2.0 kW; the Micro DSM features 1.0, 2.0, 3.0, and 7.5 kW. The YSM servo motors feature metric mounting dimensions; the NSM feature NEMA 23 to 56 mounting dimensions.

For More Information Write In No. 717

Meritec, Painesville, OH, offers a 50-position male to 68-position female **interface adapter**, which allows interfacing between SCSI-1 and SCSI-3 devices, eliminating the need for multiple cable assembly configurations. The 68-position adapter is available with or without latch posts to facilitate mating and unmating of the cable to the chassis.

For More Information Write In No. 714

New on the Market

Hoffman Engineering, Anoka, MN, offers the UL Type 4 **modular enclosures** with UL Type 4 ratings for use in wet, non-corrosive industrial environments. They are based on the APX modular platform and feature dust- and liquid-tight seals on the sides, top, and doors. The modular frame design comes in 42 single- or double-bay sizes.

For More Information Write In No. 716

TH Series **load cells/force sensors** from Transducer Techniques, Temecula, CA, were designed for through-hole applications such as bolt force measurements and overload monitoring. The compression-only cells are available in multiple outside diameters of 1.0", 1.5", 2.0", and 3.0", all with multiple inside diameter combinations. Capacities range from 100 lbs. to 50,000 lbs. with maximum full-scale non-linearity of ±0.5%.

For More Information Write In No. 721

Acroloop Motion Control Systems, Chanhassen, MN, offers the ACR2000 PC-bus **motion controller**, which features 32/64-bit floating point DSP, onboard data acquisition, and Windows NT 4.0 drivers. The ½-size SMT PC-bus card can control up to four axes of either servo or stepper motion control. It can be supplied with C++, Visual C, or Visual Basic libraries.

For More Information Write In No. 720

Dual-Vee LoPro **linear motion systems** from Bishop-Wisecarver Corp., Pittsburg, CA, are available in four sizes with belt, chain, lead screw, or pneumatic cylinder actuator drive options. The systems combine the Dua L Vee V-guide wheel and track components with LoPro wheel plates, track plates, drive ends, and accessories. Track lengths to 20 feet and track plates in 10-foot lengths can be assembled with staggered joints. The design allows multiple stacking in one- to three-axis applications.

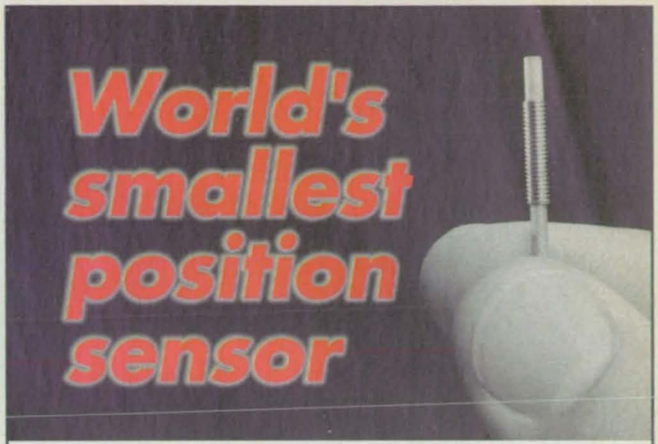
For More Information Write In No. 719

The DuraTRUE™ Series of **planetary gearheads** from Thomson Micron, Ronkonkoma, NY, provide peak torque ratings of up to 7,377 in-lbs. and backlash ratings as low as 8 arc-minutes. Frame sizes of 60, 90, 115, and 142 mm square offer ratios of 3:1, 5:1, and 10:1 in a single stage and 15:1, 25:1, 30:1, 50:1, and 100:1 in two stages. The steel gears are hardened to HRC 55-60, feature lifetime synthetic grease, and are self-lubricating.

For More Information Write In No. 723

TTI, Williston, VT, has announced the PX series of Fuji **process controllers**, which employ Fuji's patented fuzzy logic algorithms and PID autotune. The controllers learn processes, reaching setpoints quickly and eliminating overshoot. The nine models feature NEMA 4X faceplates, 24 V AC/DC or 85 to 265 V AC input power, universal input, eight-segment ramp/soak programming, and multiple security levels.

For More Information Write In No. 722



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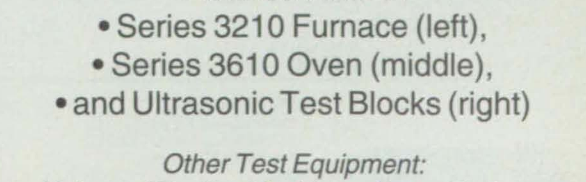

Pictured Above:
- Series 3210 Furnace (left),
- Series 3610 Oven (middle),
- and Ultrasonic Test Blocks (right)

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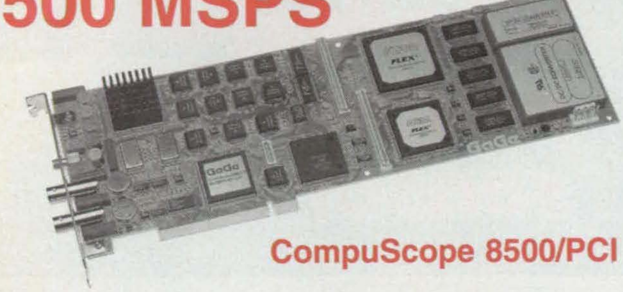

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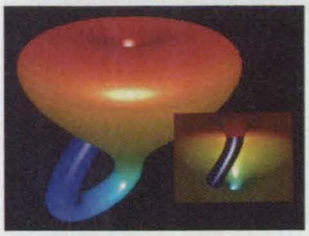
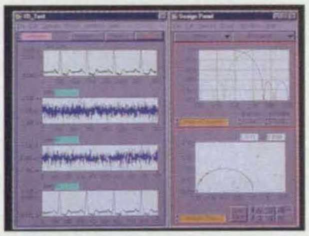


The MathWorks, Natick, MA, has introduced MATLAB 5 **technical computing software**, which provides a single environment for analysis, visualization, modeling, simulation, and large-scale application development and deployment. New features include support for multidimensional arrays and user-definable data structures; language enhancements; realistic 3D visualization and presentation graphics; application development tools such as an interactive GUI builder, browser-based documentation, and visual editor/debugger; and ODE solvers for stiff equations. It is available for Windows 95 and NT, Macintosh 68K and Power Macintosh, and UNIX platforms. Prices start at $1795.

For More Information Write In No. 725



National Instruments, Austin, TX, offers LabVIEW Wavelet and Filter Bank Design Toolkit, an add-on **design and analysis software** package that provides wavelet and filter bank analysis tools for researchers and developers in signal and image processing, computer vision, physics, and mathematics. Users can load the signal or image from a data file or acquire it using data or image acquisition hardware. The software is priced at $495.

For More Information Write In No. 729

Surfcam Version 7.0 **CAD/CAM software** from Surfware, Westlake Village, CA, enables 2D and 3D mechanical design, modeling, prototyping, mold-making, and pattern-making. New features include z-level roughing and finishing, an operations manager, support for Open-GL graphics, on-line help, DNC capabilities, a SAT file translator, and automatic parting line generation. The PC-based program is available for Windows 95 or Windows NT platforms.

For More Information Write In No. 726

PowerFLOW™ **fluid flow analysis and simulation software** from Exa Corp., Lexington, MA, allows engineers to perform complex fluid flow problems on workstations by computing 3D flow fields. MCAD files can be imported from Pro/ENGINEER® or other systems for specification of fluid flow problem parameters. The software then builds a 3D simulation of results that can be displayed in streamlines and ribbons, vectors, isosurfaces, and isolines. The program operates on Sun UltraSPARC and Enterprise server systems; prices start at $15,000 per seat.

For More Information Write In No. 730

Silma Division of Adept Technology, San Jose, CA, has introduced CimStation Inspection **coordinate measuring machine (CMM) programming software**, which enables users to program CMMs directly from CAD without waiting for physical parts or taking CMMs out of production to program them. The software interfaces with many popular CAD programs and is available for Windows NT version 4.0.

For More Information Write In No. 727

SEER-DFM **product development software** from G A SEER Technologies, Los Angeles, CA, enables product development, cost estimating, and design improvements for integrated circuits, plastic molding, fabrication, machining, electrical or mechanical assembly, or other manufacturing projects. Cost allocation, analysis, and risk charts, as well as quality analysis, cost estimates, and recommendations are provided.

For More Information Write In No. 728

Engineering Software, Germantown, MD, has introduced Power Systems Analysis 1.0 **power system design and management software**, which calculates thermodynamic and transport properties of gaseous, liquid, and solid species, and analyzes power cycles and power cycle components and processes. Physical properties of available species are provided in U.S. and international units. The program runs with Windows 3.1, 3.11, or 95 and requires 4 MB of RAM and 4 MB of hard disk space.

For More Information Write In No. 731

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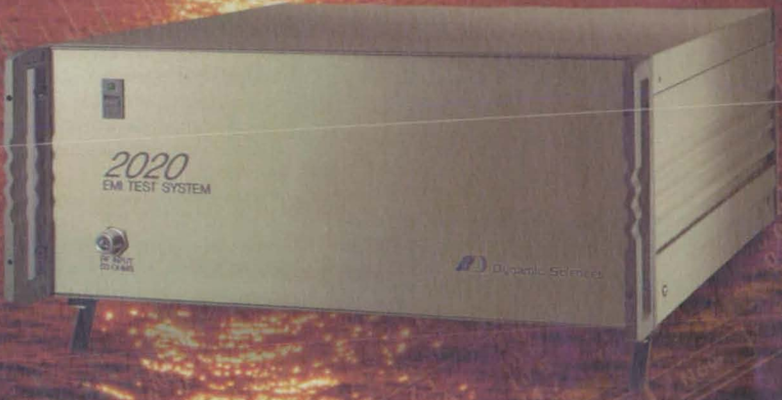

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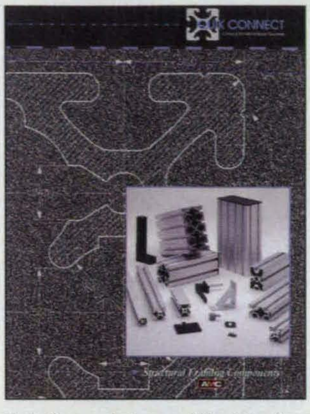


Quik Connect, Auburn Hills, MI, offers a six-page brochure describing modular structural **framing components** for workstations and workbenches, tables, conveyors, stands, enclosures, and cabinets. They are made of anodized industrial grade aluminum alloy.

For More Information Write In No. 700

A 16-page brochure on Pneuma-Seal® **seals** and related equipment is available from Presray Corp., Pawling, NY. Standard seals, end configurations, clamps, corners, custom rubber fabrications, inflatable seals, and compression gaskets are described.

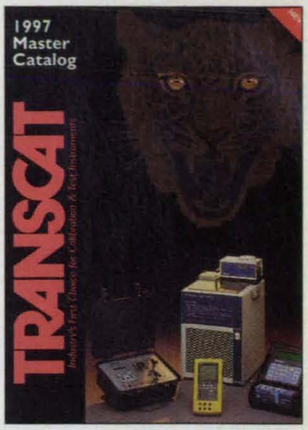
For More Information Write In No. 701

Design, development, and production of engineered **plastic parts and assemblies** are described in a six-page brochure from Plastics Technology Center, Lexington, KY. Featured are services such as 3D computer-aided design, electronic prototyping, production tooling, and plastics process simulation.

For More Information Write In No. 703

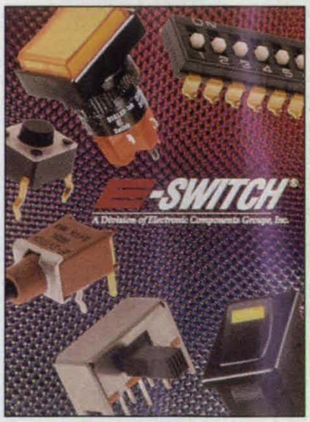
Kinetic Systems Corp., Lockport, IL, offers a 20-page brochure describing **data acquisition and control products** for the VXIbus. Included are analog-to-digital converters, signal conditioners, computer interfaces, digital I/O, mainframes, and data acquisition and control software.

For More Information Write In No. 704



A 412-page catalog from Transcat, Rochester, NY, describes the company's line of **calibration and test instruments**. Included are electrical, electronic, temperature, pressure, and environmental test instruments; tools and general equipment; meters and analyzers; and dataloggers and software.

For More Information Write In No. 705



E-Switch, Brooklyn Park, MN, has released a 28-page catalog of **switches**, including new lines of DIP, pushbutton, slide, and gold tact switches. Also described are toggle, rocker, power, lever, slide, rotary, keylock, and illuminated switches.

For More Information Write In No. 702

Belt Technologies, Agawam, MA, has released an eight-page brochure on **pulleys**. Included is information on pulleys for use with metal belts, as well as the Independently Steerable Pulley for flat belt applications that allows mounting of several pulleys on a common shaft.

For More Information Write In No. 706

A 56-page catalog of **spiral retaining rings** is available from Smalley Steel Ring, Wheeling, IL. Featured are light, medium, and heavy duty retaining rings; WaveRings®; shims; and spring products. Engineering design information also is included.

For More Information Write In No. 707

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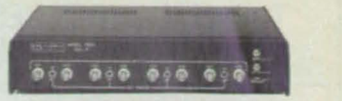

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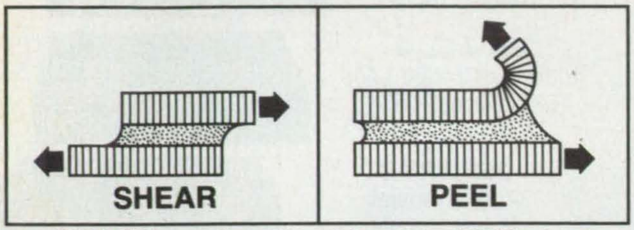

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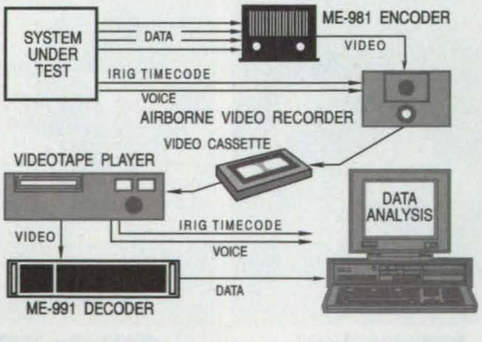

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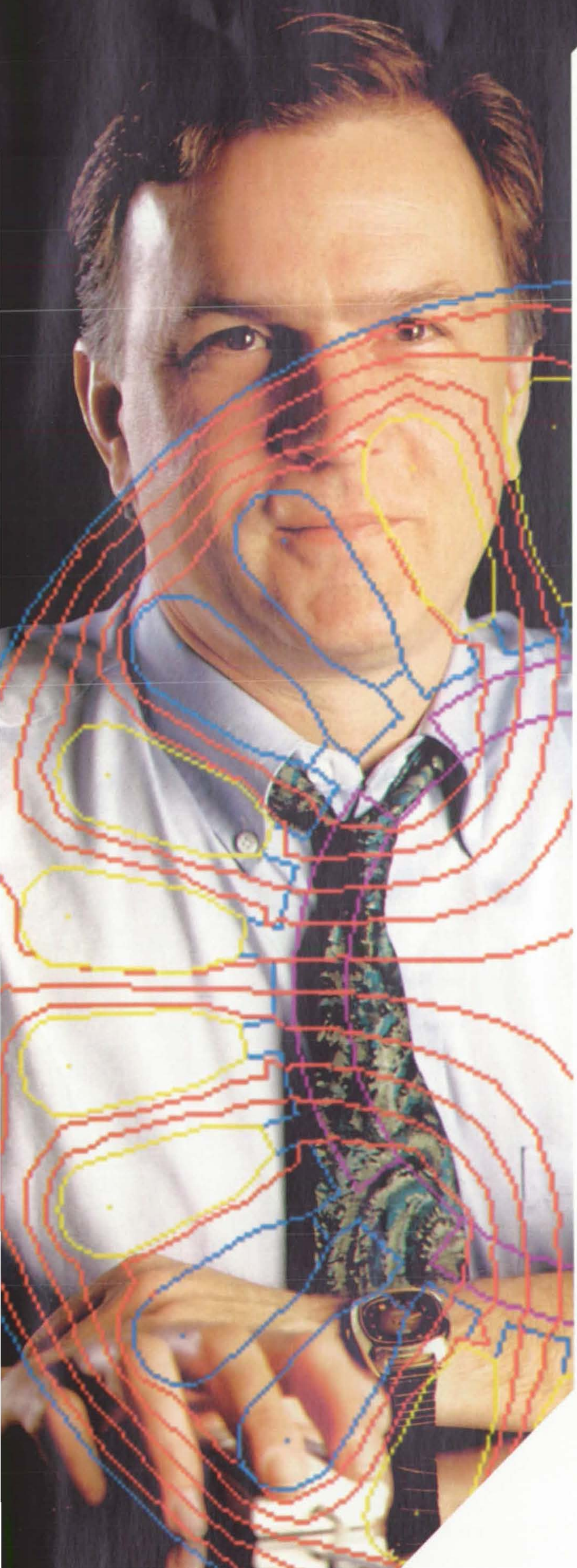

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These spectacular images were captured by the Hubble Space Telescope and processed, viewed and analyzed in IDL.

fuzzy pictures

big problem

The Hubble Space Telescope is in orbit when a defect is discovered in the primary mirror. Fuzzy pictures. Big problem.

Scientists knew they faced a daunting task when they launched the servicing mission to repair NASA's Hubble Space Telescope in 1993. They needed superior software tools to test, calibrate and analyze the data from the replacement camera. They chose IDL, the *Interactive Data Language.*

Here's why.

The ability to quickly and easily write applications, compile data and visualize results compelled the Investigation Definition Team for the WFPC-2 to use IDL as their software language. IDL provides a "powerful, flexible language that is easy to use and customize," says Paul Scowen, a team member. "With IDL you can be productively working on your data after only a couple days' exposure to the environment."

IDL helps make Hubble picture perfect

SIMPLE

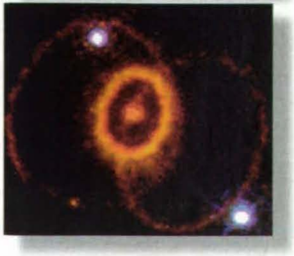
POWERFUL

FLEXIBLE

"Among other things, I put together a GUI that incorporated numerous IDL applications in a simple, point-and-click mode. IDL is one of the best environments I've seen to design GUIs quickly and easily," says Scowen.

Scowen estimates they saved "more than a year of labor over the course of three years by adopting IDL over other alternatives." Because IDL runs on Windows, Unix and Macintosh computers, the team could quickly and efficiently share their work. "Being able to take procedures written on one machine and directly transplant them to another at the drop of a hat is particularly advantageous," Scowen says.

"Many of IDL's array-handling logic routines are invaluable," Scowen adds. "For example, the ability to multiply two arrays in memory as fast as IDL does cannot be matched by other commercially-available software."



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