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Official Publication of the
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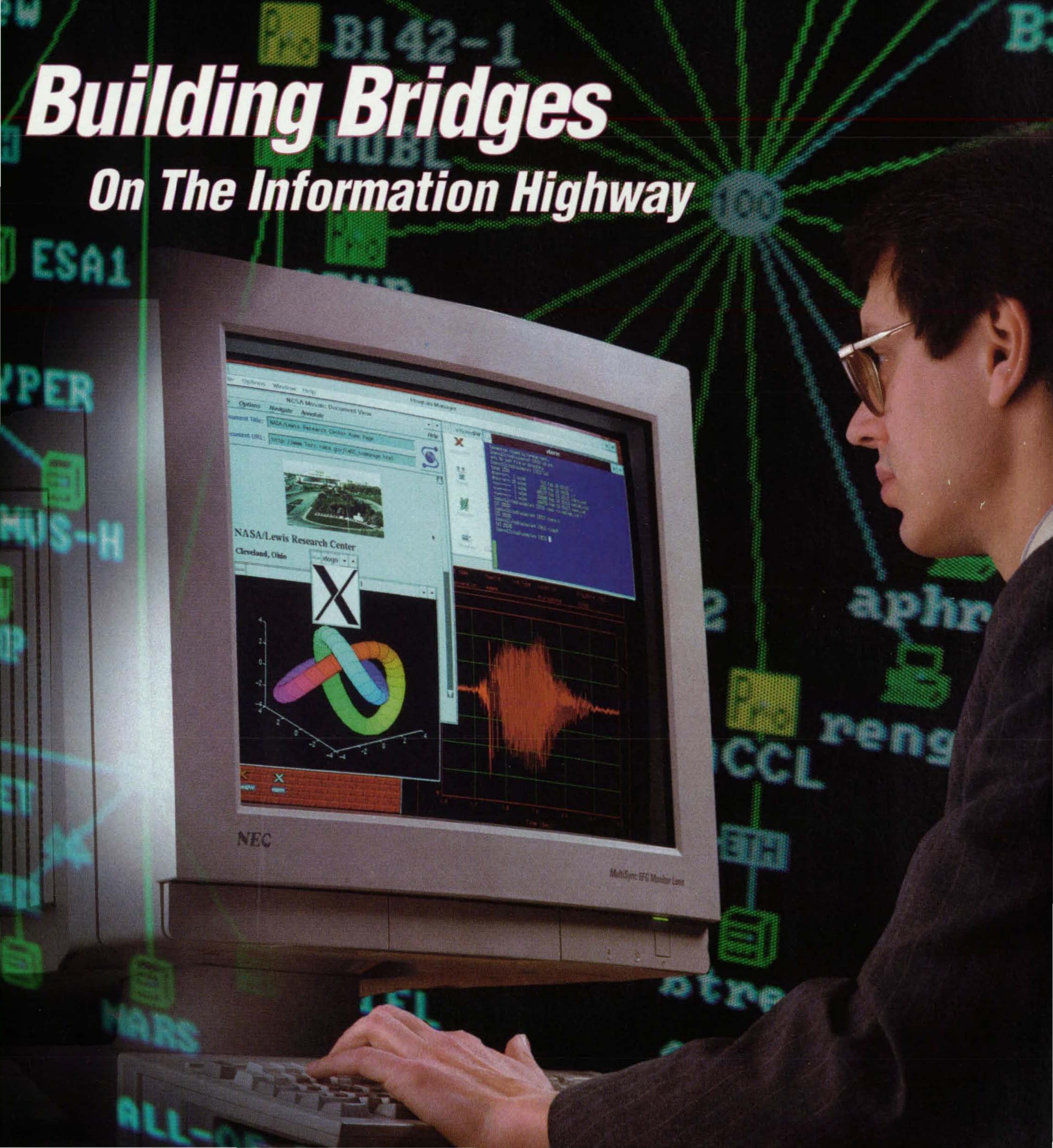

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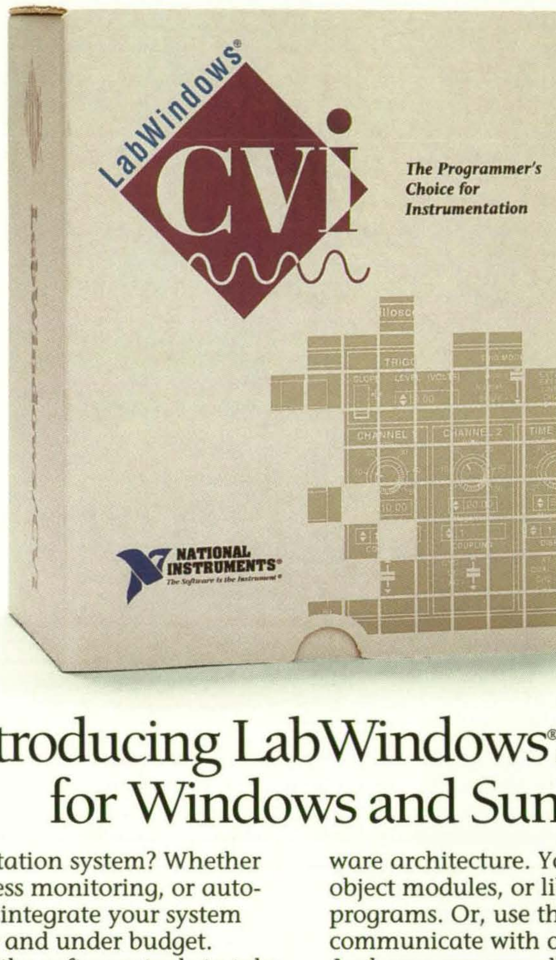

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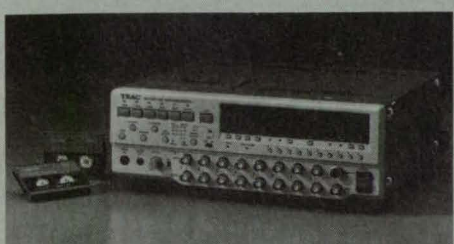

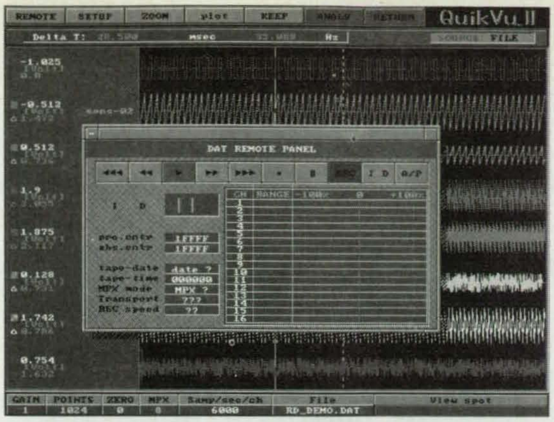

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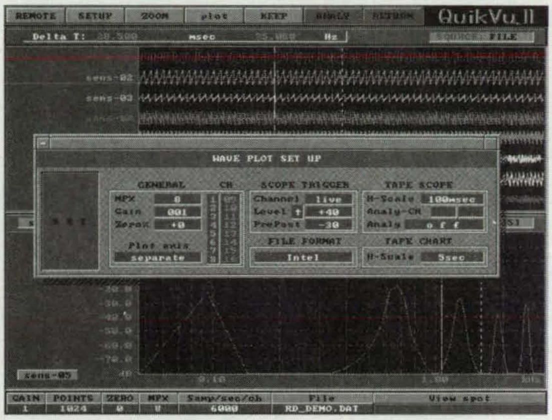

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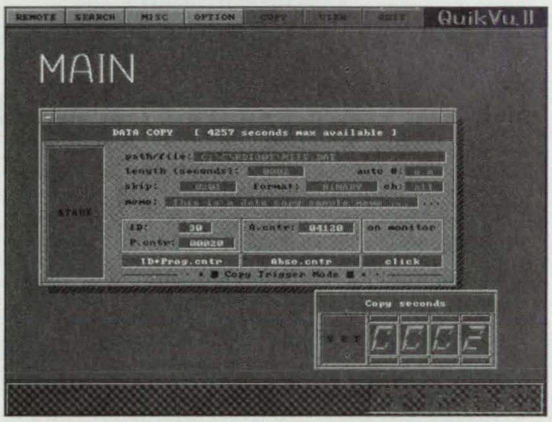

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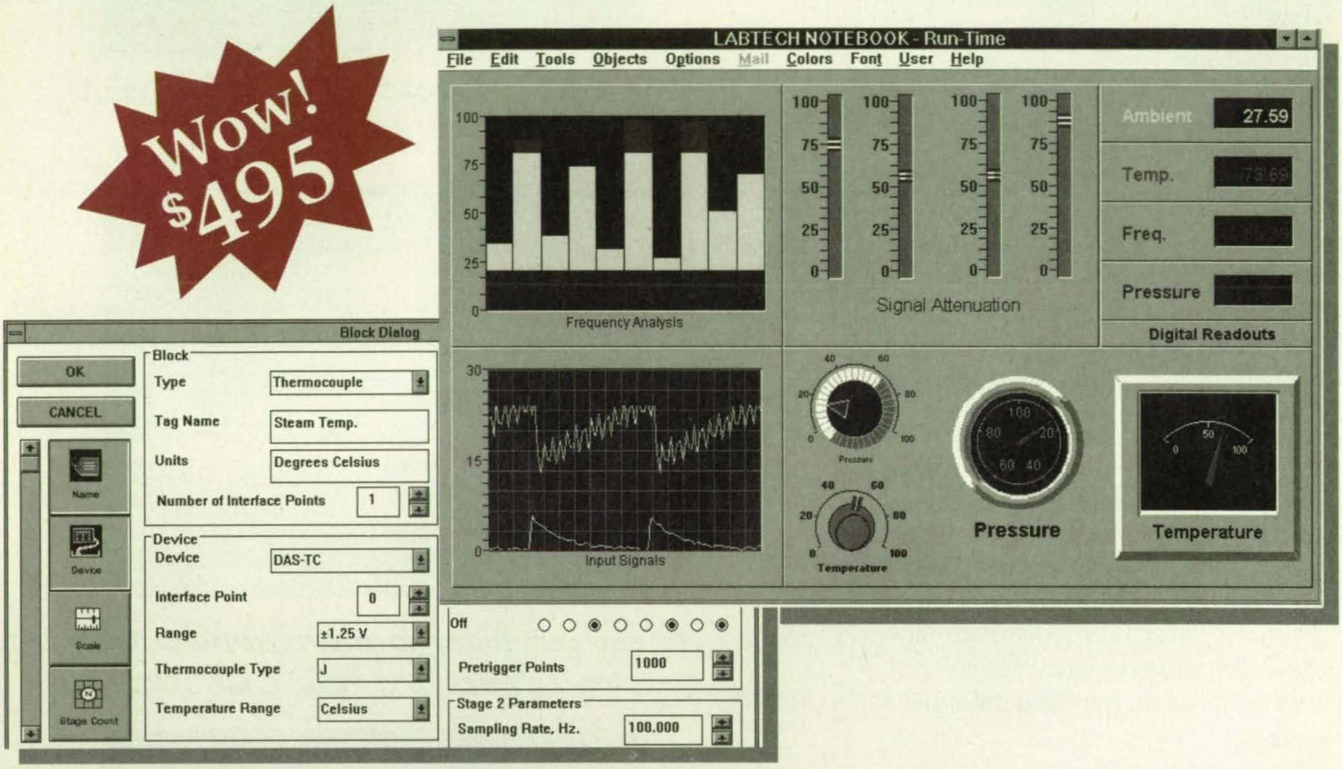

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May 1994
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Contents

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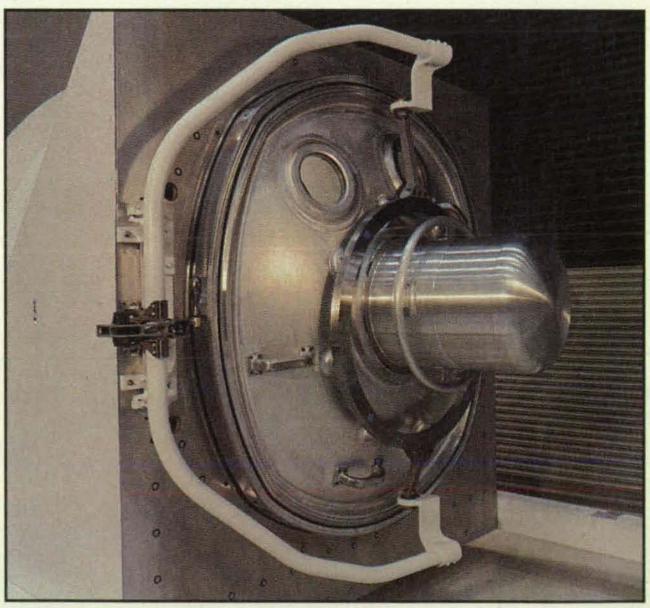
FEATURES

TECHNICAL SECTION

(continued on page 8)



Johnson Space Center engineers have designed a pressure-assisted compound seal for use on frequently opened hatches. Two elastomeric rings provide redundancy and are retained positively so that they are not pulled out when the hatch is opened. The seal makes contact with the hatch well before the hatch starts to squeeze the rings, which extends the distance over which the seal becomes engaged and provides stronger sealing action. See the tech brief on page 80.

Photo courtesy Johnson Space Center

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Contents *(continued)*

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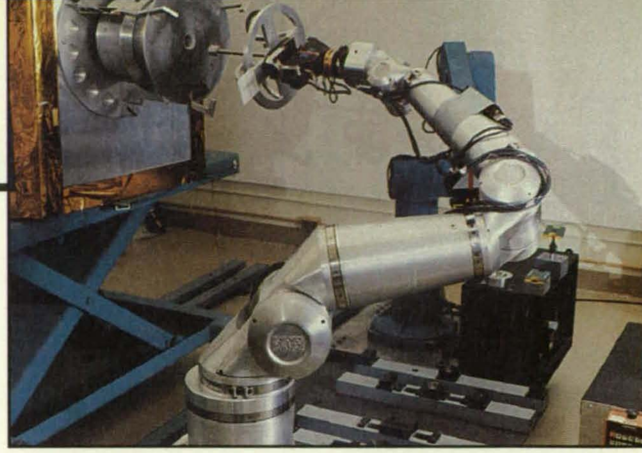

A control software system for an experimental seven-degree-of-freedom telerobot developed at the Jet Propulsion Laboratory maximizes performance through the use of multiple control modules, each of which provides parameter-driven control of specific robot functions. The software, which runs in the Ada language on multiple 68020 processors, enables simultaneous force control, trajectory generation, and collision avoidance. For more information see page 30.

Photo courtesy the Jet Propulsion Laboratory

On the cover:
PC X display server software from Hummingbird Communications Ltd., developed with help from Lewis Research Center, permits PC users to access applications across a network regardless of operating system or hardware platform. Les Farkas, a computer engineer at Lewis, demonstrates how the PC X display can be used to view simultaneously a 3D graphics application, a 2D plot of high-speed data, a network application such as NCSA Mosaic, and MS Windows. Turn to Mission Accomplished, page 12.

Photo courtesy Hummingbird Communications Ltd.

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The most comprehensive information system ever created to look at Earth will collect vital data from numerous Earth-monitoring systems, provide it to scientists worldwide, and store it in archival centers. This system, called NASA's Earth Observing System Data and Information System (EOSDIS) Core System, is the "heart" of NASA's international research program, Mission to Planet Earth. Designed and developed by Hughes Aircraft Company, the Core System calls for a computer-based application of information technology that processes, stores, and retrieves massive amounts of data from EOS space platforms and other existing scientific and technical databases. The goal is to have an information system in place that will make data readily accessible so that it can be maximized in gaining a better understanding of our planet.

DirecTv subscribers will receive 70 to 90 additional channels of programming when the second DirecTv direct broadcast satellite (DBS) is launched. A General Dynamics Atlas rocket will lift a second high-power Hughes-built HS 601 satellite into orbit in the summer of 1994. With two satellites, DirecTv will offer 150 channels of news, sports, movies, and specialty television programming directly to households equipped with low-cost, 18-inch receiver antennas. The second satellite marks an important milestone in this revolutionary digital distribution system, by providing more than 100 million television households in the United States and Canada with immediate access to a variety of entertainment and information services.

Aircraft pilots will be able to read their gauges more easily, even in sharp sunlight, with an advanced cockpit display. Developed by Hughes for military airborne applications, this compact, lightweight, multi-function cockpit display unit offers improved performance and reliability. The new display incorporates a cathode ray tube display and electronics elements in a single package weighing less than 14 pounds. Compatible with Hughes' AN/AAQ-168 helicopter night vision systems, this high resolution display has a maximum brightness and can be read easily in all conditions.

An in-flight, duty free shopping program is now available for passengers aboard Northwest Airlines' 747 aircraft. As an extension of Hughes' interactive video system, called Worldlink™ by Northwest, passengers have access to view the complete Inflight Duty Free Shop selection of products through an individual screen and control unit at each seat. Passengers are able to place orders from the comfort of their seats and select their preferred method of payment — cash when the flight attendant delivers the order or credit card, using a built-in magnetic card reader. With the wide variety of entertainment, business, communications, and tourist information offered by Worldlink, passengers have control over their in-flight experience.

Four major airports in the Ukraine may be completely modernized, with advanced technology and systems built by Hughes. The plan, which would focus on airports at Kiev, Odessa, Lviv, and Symferopol, is designed to automate these airports through electronic data interchange. Its objective is to integrate aircraft operations, passenger handling, air traffic control, security, and administration into one highly efficient unit. Using computer technology can dramatically enhance an airport's efficiency and service, and help it increase revenues and adhere to more stringent regulations.

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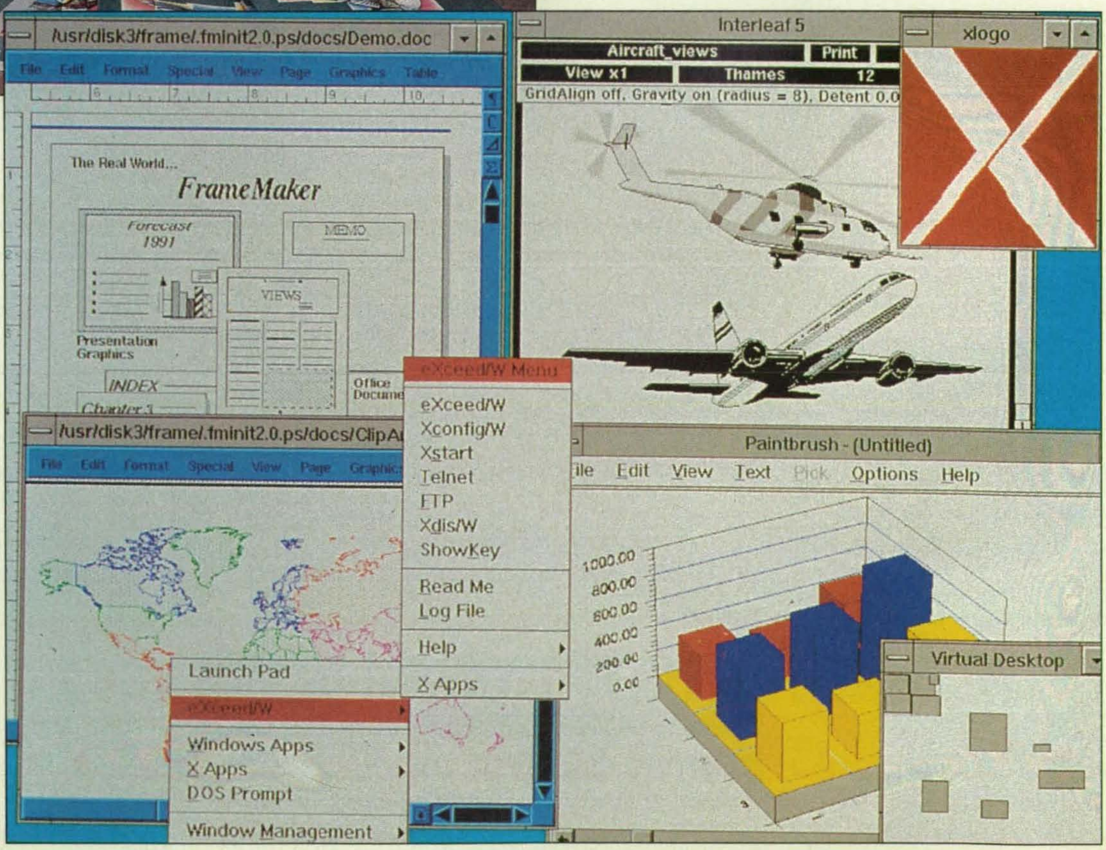
Mission Accomplished

Through the technology transfer process, many of the systems, methods, and products pioneered by NASA are reapplied in the private sector, obviating duplicate research and making a broad range of new products and services available to the public.

A major barrier to constructing an information highway, whether within organizations or among computer users across the globe, is finding a seamless means to interconnect user groups. The problem is particularly critical for large organizations seeking to network heterogeneous hardware and software used for a wide variety of computerized tasks.

Consider the example of NASA's Lewis Research Center, which conducts research in such diverse fields as aeropropulsion, space power and communications, electric propulsion, and microgravity. "We have all kinds of systems: Sun, SGI, IBM, DEC, HP, Convex, and Concurrent, as well as the Lewis Information Management System—MS-Windows-based office automation software," said Lewis computer engineer Les Farkas.

The search for a means to interconnect all of the Lewis platforms and programs started five years ago, when Farkas began evaluating the X Window System, a network graphics protocol for connecting minicomputers, mainframes, supercomputers, and workstations. Essential to networking at Lewis, according to Farkas, was tying in Lewis' roughly 5000 PC desktop computers to the UNIX community. The solution was found in X display server software for PCs from Hummingbird Communications Ltd., Ontario, Canada.



Hummingbird Communications' PC X server software, including eXceed/W for MS-Windows (above) enables PC users to view remote X Windows System and MS-Windows applications simultaneously (right).

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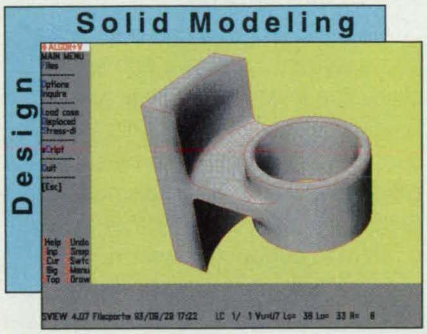

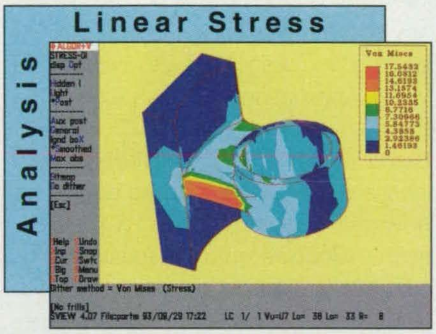

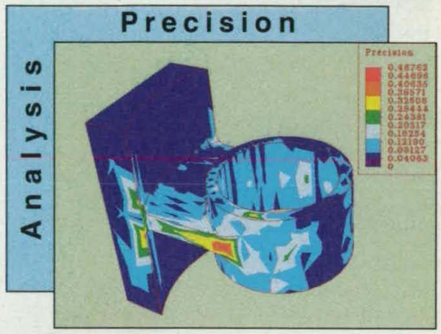

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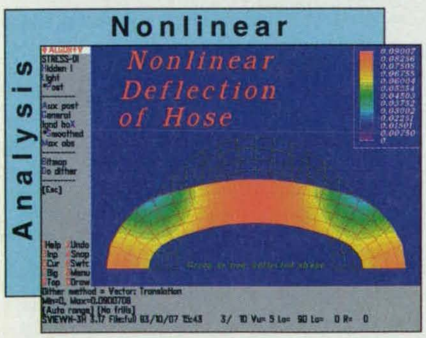

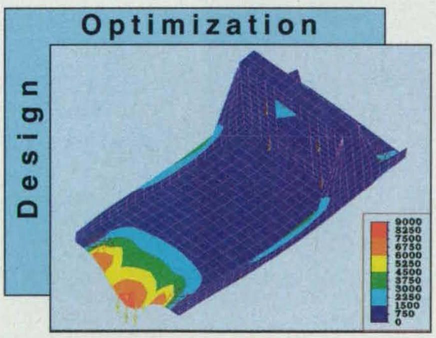

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For More Information Write In No. 566

"There's no way we could mandate that everyone at Lewis have the same machine—nor would we want to," said Farkas. "It all depends on the kind of work a person does. X provides the least common denominator—basically, your computer is your network."

The X Window System is a windowing environment born of two university research projects in the early 1980s. Project W at Stanford and Project Athena at the Massachusetts Institute of Technology, with funding from Digital Equipment Corp. and IBM, developed an independent graphics protocol to provide interoperability between the universities' disparate computing platforms. Designed to work under any operating system, X permits graphics generated in one system to be displayed on another network workstation.

On the commercial market just six years, X display server software for PCs permits access to all X Window System applications regardless of operating system, hardware platform, or network protocol. The user can interact with several X applications simultaneously in separate windows on the PC screen—running applications in UNIX, VMS, AIX, Solaris, Ultrix, and other X Window System hosts concurrently with local PC applications based on DOS, MS-Windows, or Windows NT operating systems. The physical locations of the applications remain transparent.

PC X servers offer a means to distribute the processing power of UNIX, for example, without incurring the expense and learning time associated with switching to UNIX. Applications such as CAD/CAM that normally would require a costly RISC-based workstation can be viewed on an inexpensive PC while they are running on powerful workstations. PC X provides similar windows onto databases, mapping and geographical information systems, visualization and simulation, structural analysis, electronic publishing, system administration and network management, office automation, E-mail, process control, transaction processing, spreadsheets, mathematics, and statistics.

NASA Advice Helps Product Hum

Founded in 1984 as an engineering consulting company, Hummingbird launched its first PC X server software package in September 1989. Currently, Hummingbird's eXceed line of PC X server software includes versions for MS-Windows, Windows NT, DOS, and OS/2. In addition to the X servers, Hummingbird offers X development toolkits that include porting and programming tools.

NASA Lewis was one of Hummingbird's earliest customers and served as product reviewer. "In the early stages, the products were still embryonic," recalled Jan Adamek, Hummingbird senior vice president. "The Lewis people had a lot of experience and knew what they wanted.

"NASA suggested we dramatically improve the cut-and-paste feature. We knew it was important, but the way we had it—and the way our competitors still have it—was to send cut sections to an intermediate clipboard. NASA advised us to reduce the steps, so now you just select the text from one file and copy it to

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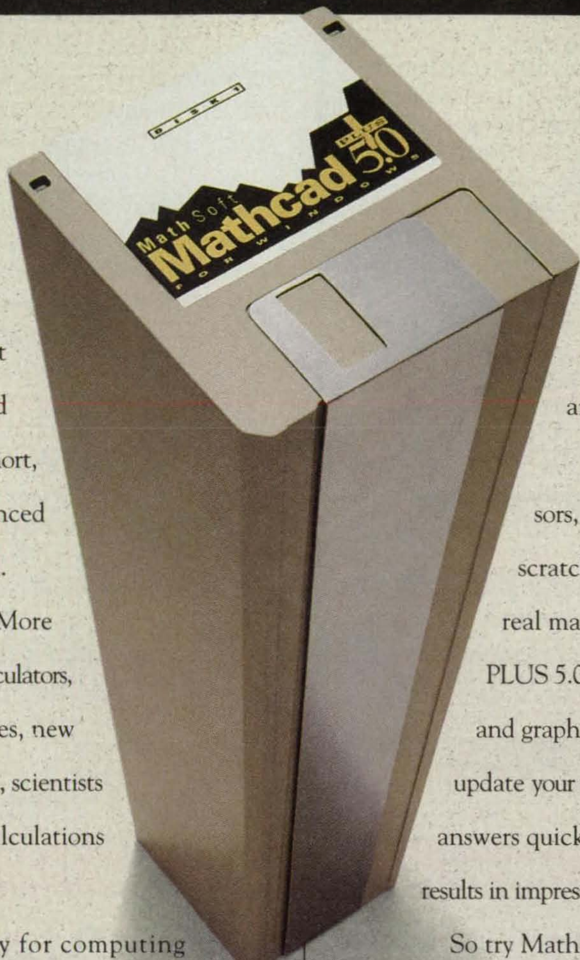

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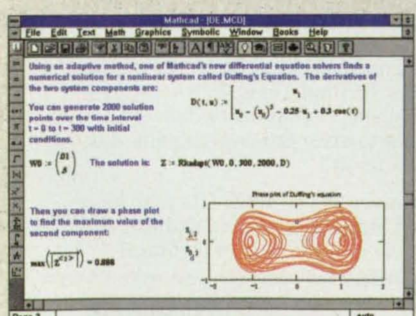

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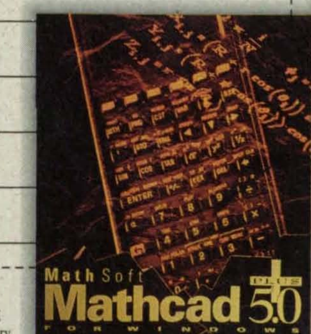

For More Information Write In No. 650

another—two steps instead of five," explained Adamek.

Hummingbird's latest release, available this month, is eXceed 4 for MS-Windows, based on a high-performance 32-bit X server designed for use with high-speed microprocessors such as the Intel 80486 and Pentium. The new version eases installation and administration by integrating X server and TCP/IP (transmission control product/Internet protocol) network software—a single copy can be installed and updated on a file server. It is also the first PC X server to include a scripting language, called eXceed BASIC, which allows network managers to easily design programs for managing large populations of PCs.

Release 4 also features eXceed/Xpress, a licensed version of Tektronix' Serial Xpress, the fastest dial-up technology available. The specialized X compression technique allows PC and laptop users to remotely access UNIX and X Window System applications and hosts via standard telephone lines with a modem or RS-232 serial connections. Another feature called Xtrace serves as a client debugger, allowing the user to view in symbolic language all the traffic between the PC and other platforms and quickly pinpoint where the problem lies. ❑

For more information about the technology described in this article, contact Lorraine Neal, Public Relations Officer, Hummingbird Communications Ltd., 2900 John Street, Unit 4, Markham, Ontario, Canada L3R 5G3. Tel: 905-470-1203, Fax: 905-470-1207.

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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 Technology Utilization Office of the sponsoring NASA center (see page 20). NASA's patent-licensing program to encourage commercial development is described on page 20.

Multiple-Segment Climbing Robots

Multiple-segment climbing robots are being developed to perform such tasks as inspection, sandblasting, welding, and painting on towers and other structures. Imitating a successful natural design, these robots look and move line caterpillars.
(See page 26)

Autozero Unit

An eight-channel signal processor — an autozero unit — suppresses the dc component of an analog voltage signal that varies with time in a complicated way, without introducing phase shift into the ac component. This autozero unit would be installed in an instrumentation system between a signal source and data-acquisition equipment.
(See page 43)

Synthesis of a Precursor of Silicon Nitride

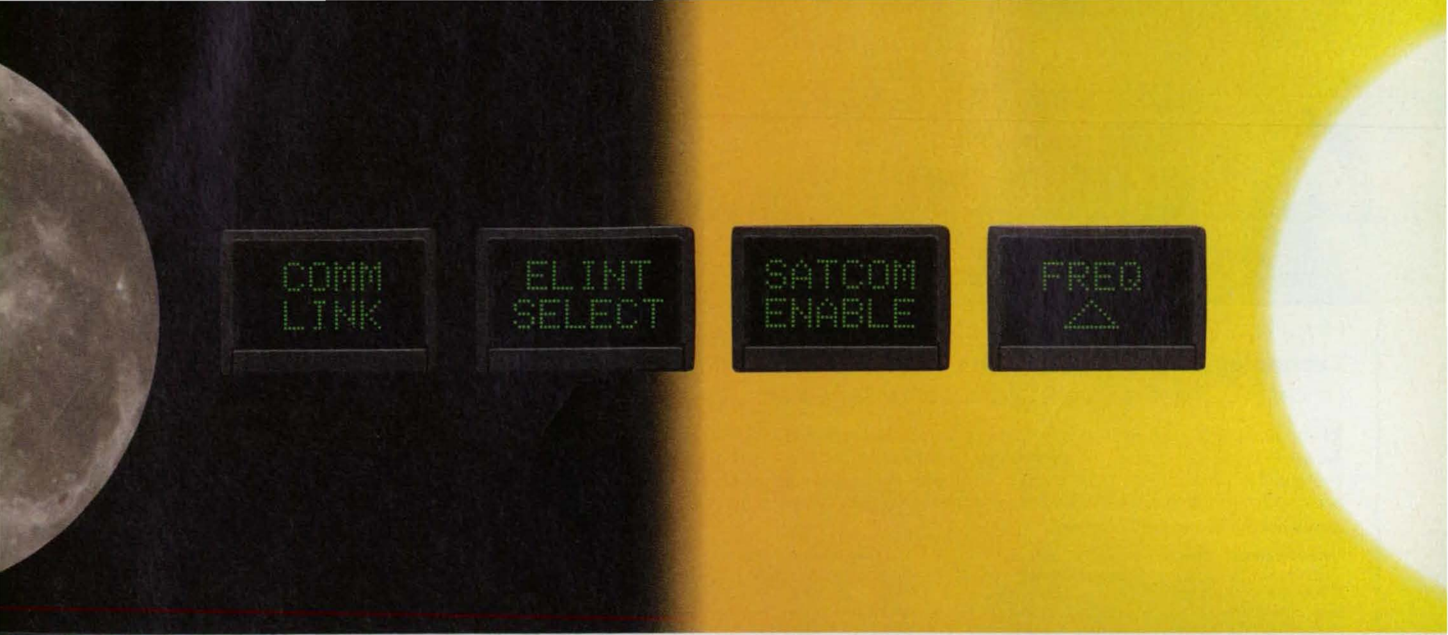
A method of producing highly pure, easily sinterable silicon nitride involves the thermal decomposition of silicon diimide[Si$(NH)_2$] prepared by the ammonolisys of Si(SCN)4 in CH_3CN and purified by the complete extraction of byproduct NH_4SCN by the use of ammonia at a temperature and pressure above its critical point. This new procedure emerged in the context of trying to devise a more efficient way to extract the chloride byproduct.
(See page 66)

Monolithic Three-Stage 32-GHz Power Amplifier

A three-stage monolithic integrated-circuit power amplifier, which operates at frequencies around 32 GHz, is designed for use aboard a communication satellite and is also suitable for terrestrial applications in which moderate power and high efficiency are needed. The power amplifier is compact and offers state of the art performance.
(See page 38)

Advanced Teleoperator Control System

A proposed teleoperator control system would incorporate several advanced features to improve coordination between the remote robotic manipulator and the human operator at the control manipulator. The system is designed with consideration of the human operator in the control look by use of a two-part mathematical model of the dynamics involved in the operator's generation of control commands in response to visual and kinematic stimuli.
(See page 22)



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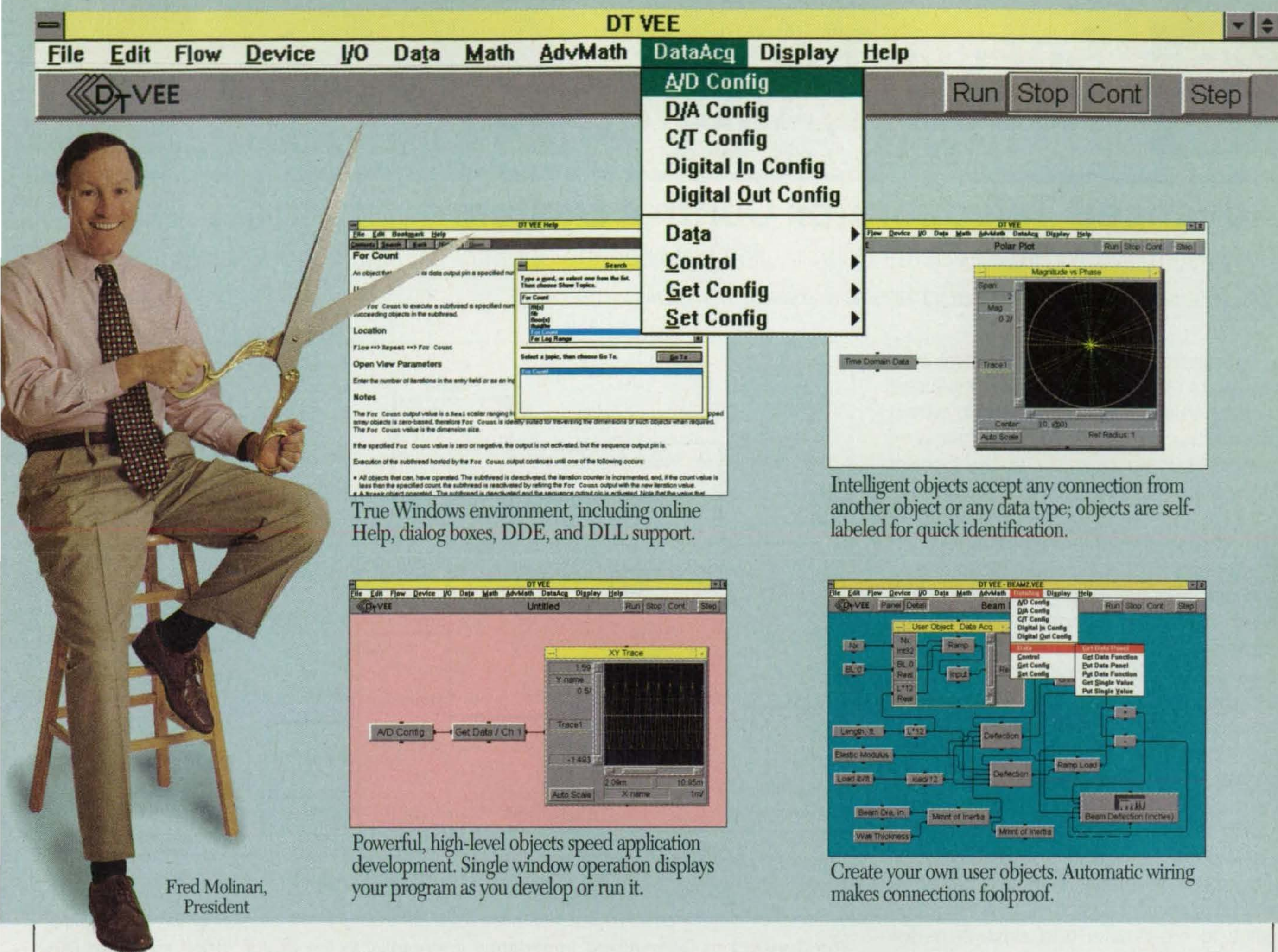

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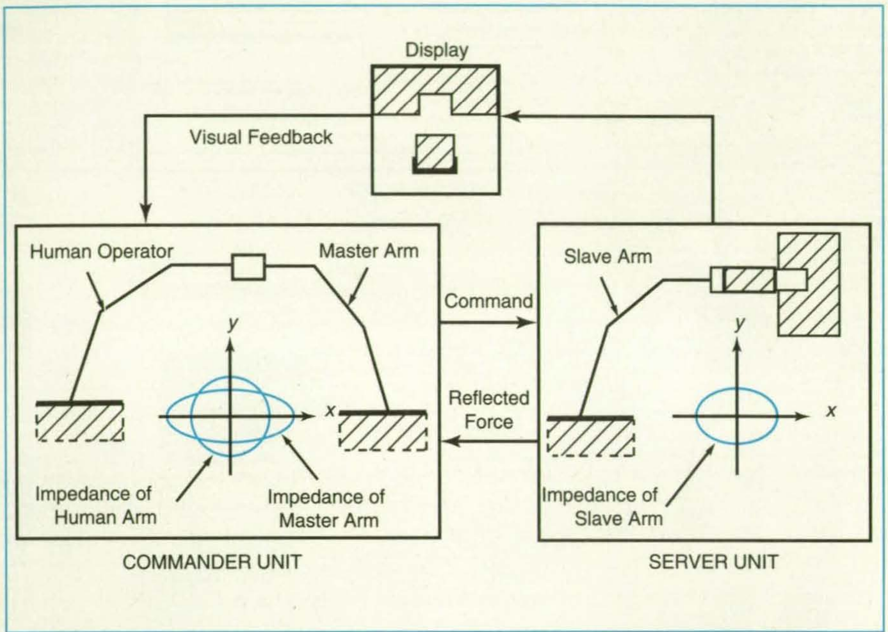
For More Information Write In No. 558

Advanced Teleoperator Control System

The system would provide better coordination between the operator and the remote manipulator.

NASA's Jet Propulsion Laboratory, Pasadena, California



The **Concept of Generalized Impedance** is essential to the design of the advanced teleoperator control system. The control system would strive to maintain the desired generalized impedances of the master and slave arms.

A proposed teleoperator control system would incorporate several advanced features to improve coordination between the remote robotic manipulator (slave arm) and the human operator at the control manipulator (master arm). The system is designed to make the operator's manual control robust in the presence of (1) such nonlinearities as saturation of actuators and delays in the propagation of feedforward and feedback control signals and (2) errors made by the operator in reacting to visual and force feedback. The system is also designed to support high-performance teleoperation while reducing the operator's control burden by (1) enabling the control subsystem at the slave arm to perform automatically such control tasks as compliance and force control (for optimization of interactions between the slave arm and the objects in its environment) and (2) imparting desirable dynamic properties to the master and slave arms for the operator's ease and comfort.

The system is designed with consideration of the human operator in the control loop, by use of a two-part mathematical model of the dynamics involved in the operator's generation of control commands, in response to visual and kinesthetic stimuli. One part of this model represents the dynamics of the physiological mechanisms by which the operator intentionally applies force to the master arm in response to the discrepancy between the current and goal positions displayed on a video screen and to the error between the actual and desired force as perceived via force feedback. The other part of the model represents the generation of the displacement of the master arm as a result of the human intentional force applied to the human and master arms combined in a parallel structure. This model provides the means to take account of human control errors in the design to provide greater robustness.

The control system would actively modify the dynamics of the master and slave arms to obtain the desired dynamic characteristics. For this purpose, the design incorporates the concept of generalized impedance (see figure), which is a transfer-function-matrix representation of the relationship between position error and contact-force error in Cartesian space. The desired dynamic characteristics would be expressed in terms of generalized impedances, and the control subsystem of each arm would strive to impose those characteristics on the motion of the arm.

To achieve proper coordination between the operator and the manipulator in this scheme in which they share control tasks, force feedback is reformulated in the design to consist of a combination of slave-arm position and force errors. As used here, "position error" means the discrepancy between the position command generated by the master arm and the actual position of the slave arm, and "force error" means the discrepancy between the desired force specified in the generalized impedance and the actual force sensed by the slave arm. Position and force errors are relevant to the coordination problem as follows: When the slave arm performs with automatic force control within the framework of generalized impedance, the direct feedback, to the operator, of force sensed by the slave arm may confuse the operator in the effort to evaluate a position command, because the operator then feels what the slave arm feels without understanding the control action performed by the slave arm. The operator could continuously extend the position error without noticing it. The reformulated force-feedback scheme of the system would solve this problem by providing the operator with a kinesthetic indication of position error.

The system has been tested by computer simulation. The results of the simulation indicate that the system provides superior performance in terms of error profiles and task-completion time in the presence of human control errors that vary over a wide range. The system is even able to maintain stability under large signal-propagation delays. Therefore, it appears that the system would be highly robust in the presence of nonlinearities and incorrect human commands in both position and rate modes of control.

This work was done by Sukhan Lee of Caltech and Hahk Sung Lee of the University of Southern California for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 33*** *on the TSP Request Card.*
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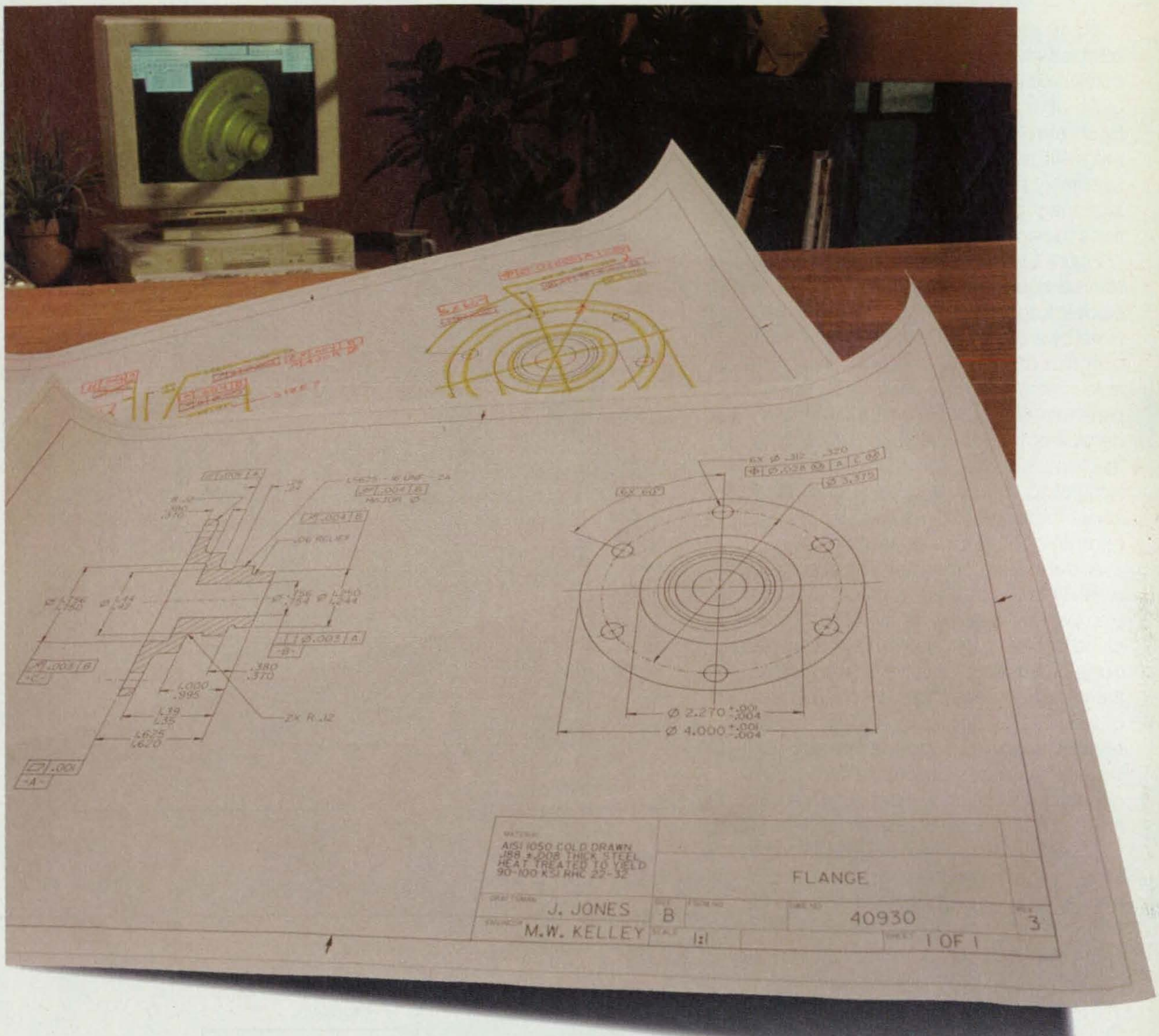

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Serpentine Robot Arm Contains Electromagnetic Actuators

The arm can be configured flexibly to avoid obstacles.

Goddard Space Flight Center, Greenbelt, Maryland

Many identical modules can be assembled into a flexible robot arm that can be configured in serpentlike fashion to manipulate objects while avoiding obstacles. Each module includes integral electromagnetic actuators that can be energized selectively to produce a variety of motions, stationary configurations, and combinations thereof.

Figure 1 shows three modules at the anchored end of the arm. Each module includes a top plate connected to a base plate by a ball joint. Both plates are made of iron or other highly magnetically permeable metal, and the base plate holds a peripheral array of electromagnets. The underside of the top plate is beveled. When the top plate is at the limit of its tilt with respect to the base plate, it can nutate about the base plate, its axis describing a cone about the axis base plate.

A permanent magnet shaped like a washer provides a magnetic flux that clamps the rim of the top plate to the pole piece of one of the electromagnets when none of the electromagnets is energized: this provides for the stationary configuration of the affected part of the robot arm. The relative angular position of the top and base plates is measured by a ring array of capacitive position sensors placed just inside the ring array of electromagnets.

An electronic controller supplies electrical current selectively to the electromagnet coils in response to commands and to the second angular position (see Figure 2). For example, the plate can be made to nutate continuously by energizing the coils in series in groups of three such that the electromagnet(s) on one side of the present point of minimum gap interact(s) with the permanent magnet to attract the rim, while those on the other side repel the rim. This effect provides torque to continue the nutation. Thus, the system functions as a permanent-magnet motor in which the top plate is the rotor and the base plate is the stator, except that the motion is nutation instead of the more common rotation about a single axis.

This work was done by Israel A. Moya and Philip A. Studer 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 [see page 20]. Refer to GSC-13161.

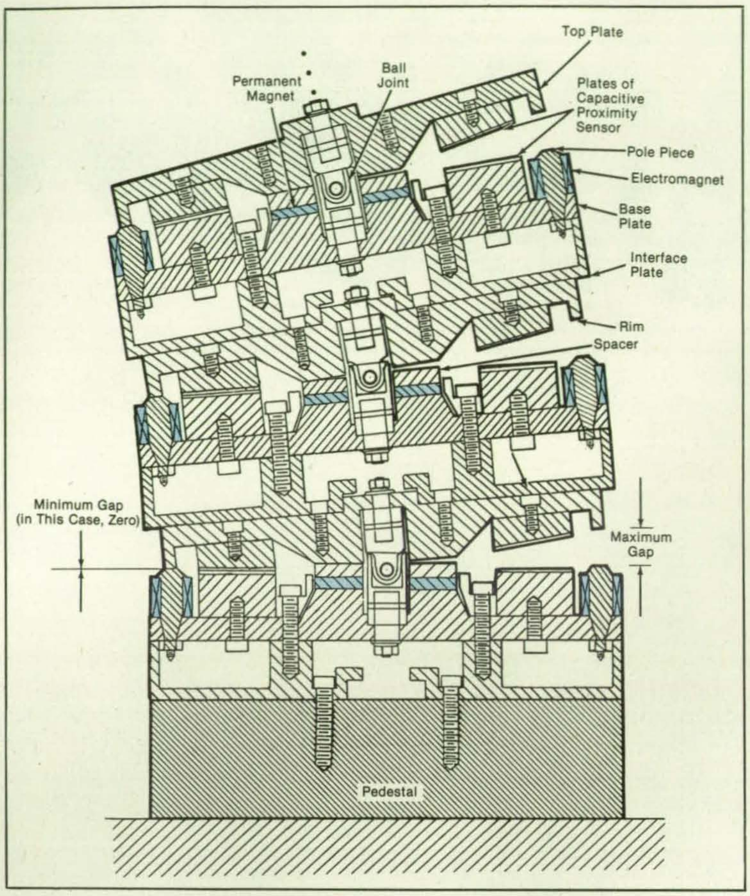

Figure 1. Identical Modules containing electromagnetic actuators are assembled into a serpentlike robot arm. Each top plate can be made to nutate about a base plate or to remain in a commanded tilt position by selectively energizing or deenergizing electromagnet coils.

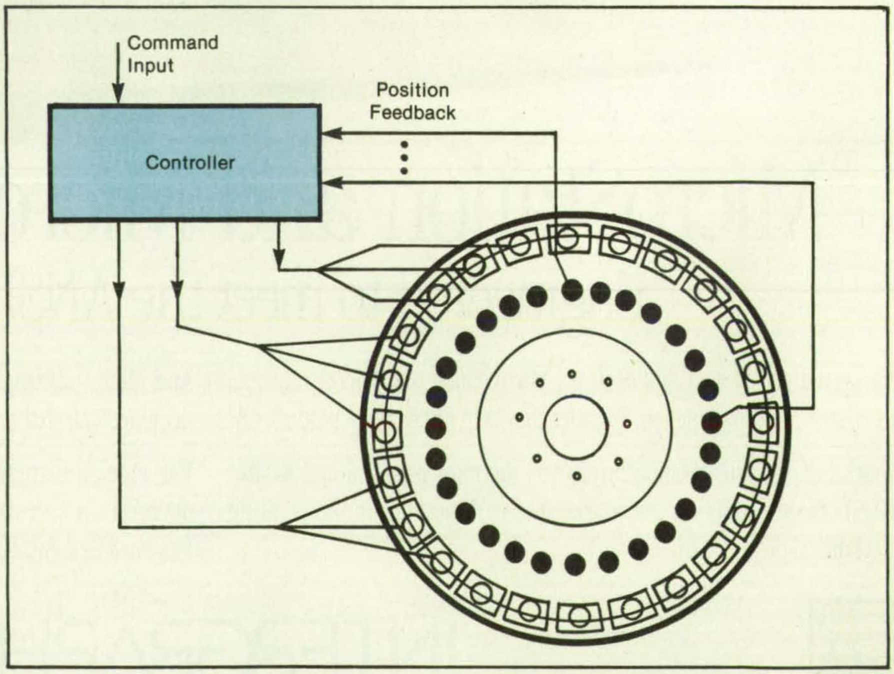

Figure 2. The **Electronic Controller** energizes electromagnet coils in groups of three to produce the commanded nutation.

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These robots look and move like caterpillars.

Goddard Space Flight Center, Greenbelt, Maryland

Multiple-segment climbing robots are being developed to perform such tasks as inspection, sandblasting, welding, and painting on towers and other structures. Imitating a successful natural design, these robots look and move like caterpillars.

Figure 1 shows a 20-segment robot moving along an angled structural member. Each segment includes a foot, which grips the member with a suction cup, electromagnet, mechanical actuator, or other device that is energized on command by a control system. Each segment contains a compliant joint made of segments of cable and retainers; the joint holds the segment together, yet allows enough twisting and bending to accommodate caterpillarlike motion.

Each segment contains a set of pneumatic, electric, or hydraulic actuators that are mounted to effect lengthwise expansion or contraction of the segment. For example, to bend the segment away from the structural member as it approaches a bolthead or other obstacle, the actuators on the side farthest from the structural member are contracted, and/or those on the side nearest the member are expanded. The following is an example of straight walking: In one step, all the segments except one grip the member, while the actuators in the lone nongripping member are expanded or contracted to move its foot forward. In the next step, the process is repeated except that the segment that moves forward is the one immediately behind the one that moved before. Thus, a wave of forward motion propagates along the robot, in a manner reminiscent of a worm or caterpillar.

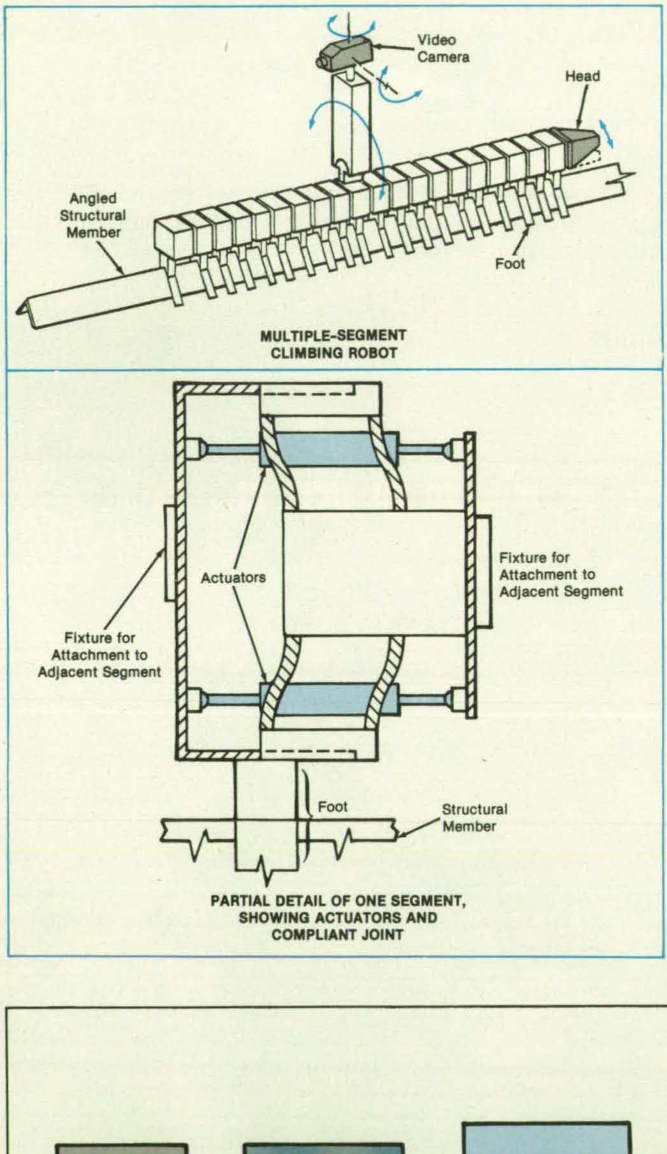

Figure 1. The Multiple-Segment Robot grips the structural member and moves along it like a caterpillar.

A video camera mounted on one of the segments can be rotated to the desired viewing angle. This camera can be used in remote inspection of a structure, to view the motion of the robot and/or provide video feedback for control of the motion, and/or to guide the operation of a head that is mounted on the foremost segment with motorized actuators. The head performs the sandblasting, welding, painting, or other special task assigned to the robot.

Figure 2 is a block diagram of a distributed control system that would be used in an advanced caterpillar robot. Each segment would contain a programmable logic device (PLD), which would receive commands from a control computer, perform the local, low-level control computations, and interact with the actuators and sensors (if any) of the segment. A controller/communicator module on the robot would handle communications between the segments and the control computer. A fiber-optic, radio, infrared, or wire communication link could be used.

This work was done by James Kerley, Edward May, and Wayne Eklund of **Goddard Space Flight Center**. *For further information,* ***write in 45*** *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 [see page 20].

Refer to GSC-13442.

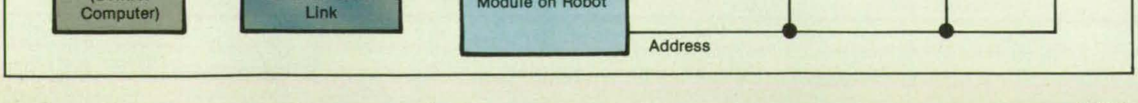

Figure 2. The **Control System** of an advanced multiple-segment robot would be modular and distributed. Low-level control logic would reside in each segment.

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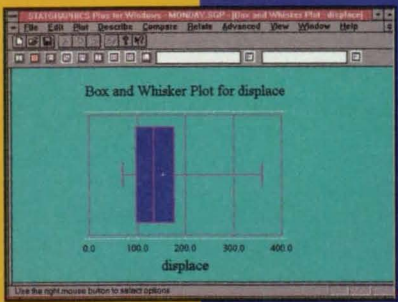

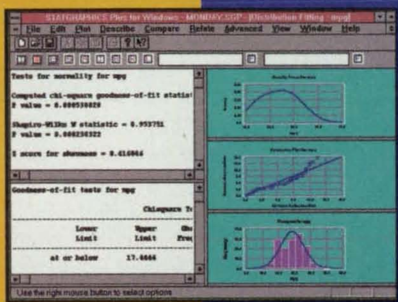

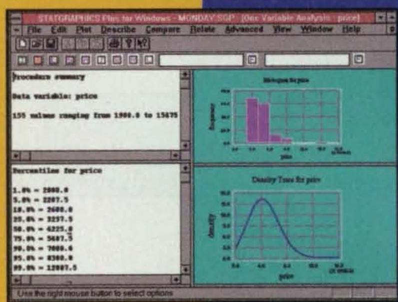

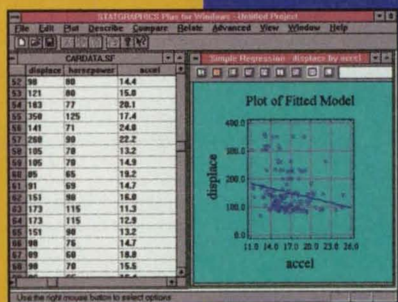

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Adaptive Impedance Control of Redundant Manipulators

Knowledge of complicated dynamical models and inverse kinematic transformations is unnecessary.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved method of controlling the mechanical impedance of the end effector of a redundant robotic manipulator is based on adaptive-control theory. A control system according to this method (see figure) is developed by considering the end-effector-impedance-control problem separately from the redundancy-resolution problem. Thus, the control system consists of two subsystems: (1) an adaptive impedance controller that generates the force-control inputs in the Cartesian space of the end effector to provide the desired end-effector-impedance characteristics, and (2) a subsystem that implements an algorithm that maps these force-control inputs into torques to be applied to the joints of the manipulator.

The Cartesian-space impedance controller is developed according to the model-reference adaptive-control approach, and does not depend on knowledge of the complicated dynamical model of the robot or values of the parameters of the robot, payload, or environment. Furthermore, the impedance controller can be implemented without calculating the inverse kinematic transformation of the robot. As a result, the method is very general and is computationally efficient.

The impedance-control problem has a unique solution even if the manipulator has redundant degrees of freedom. Redundancy becomes an issue in that it introduces indeterminacy into the problem of how to map the force-control inputs into the joint torques. As in some manipulator-control methods described previously in *NASA Tech Briefs*, the redundancy is used in this method to improve the kinematic or dynamic performance of the manipulator. The redundancy is resolved, in a departure from conventional approaches, by constructing a {force-control input} → {joint-torque} map in such a way as to utilize the redundancy effectively. For example, this approach can be used to maximize manipulability, globally minimize kinetic energy, make the robot more compatible with a given task, and/ or avoid obstacles in the workspace.

The method has been tested by applying it, in a computer simulation, to a planar four-degree-of-freedom manipulator like the one shown at the bottom of the figure. The results of the simulation show that accurate control of the mechanical impedance of the end effector and effective utilization of redundancy can be achieved simultaneously by use of the method. The results also indicate that the method also has potential for the use of redundancy to improve the performance of such typical impedance-control tasks as deburring edges and accommodating transitions between unconstrained and constrained motions of end effectors.

This work was done by Homayoun Seraji of Caltech and Richard D. Colbaugh and Kristin L. Glass of New Mexico State University for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 6*** *on the TSP Request Card.*

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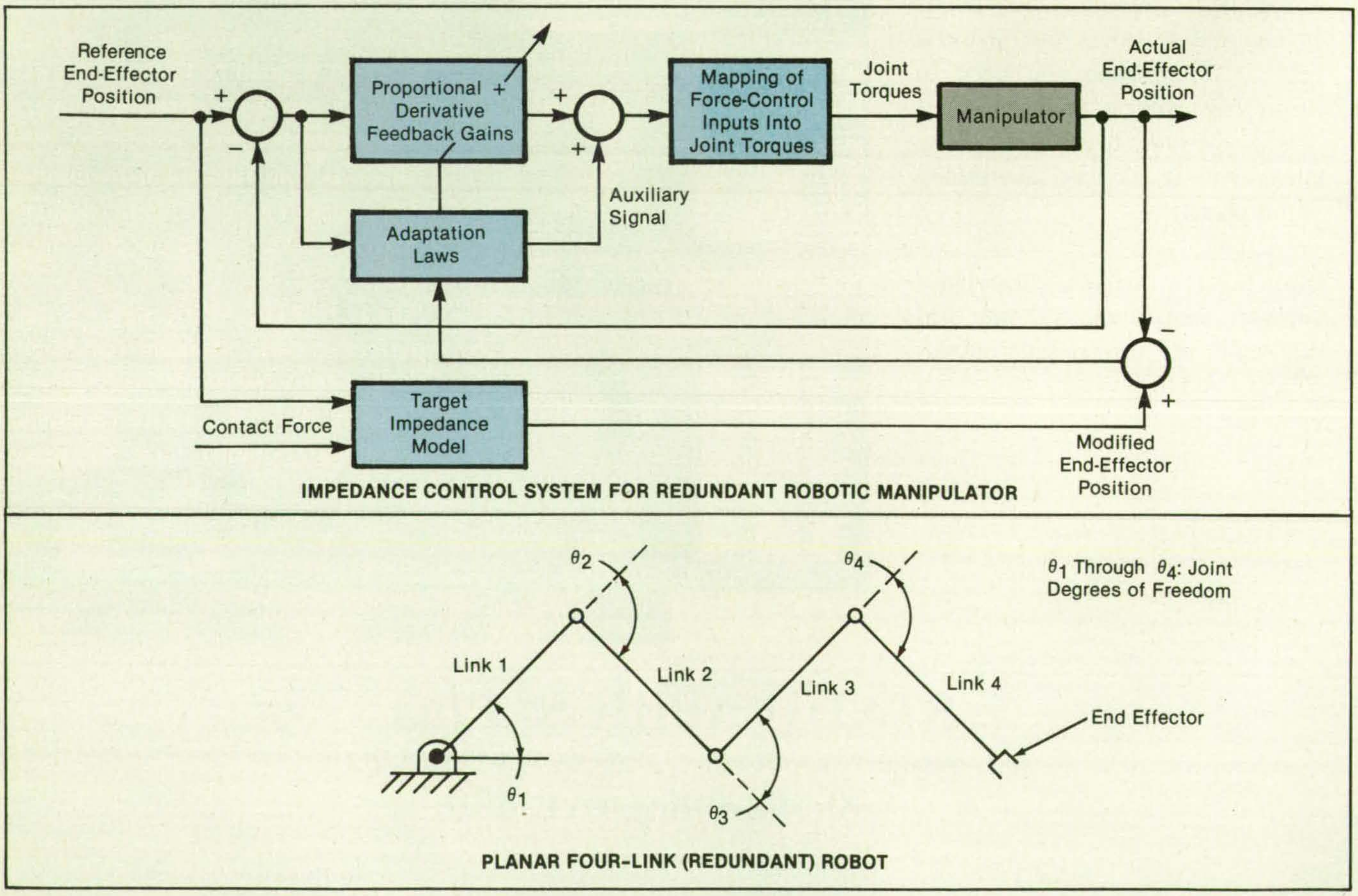
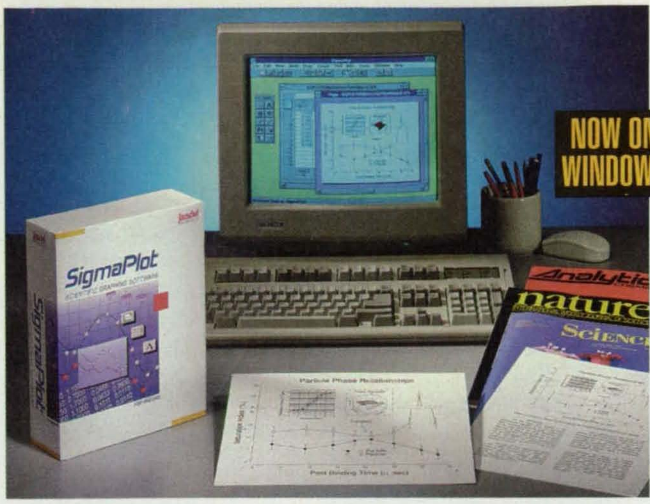


Adaptive Impedance Control, in combination with a suitable mapping scheme, provides for improved performance of a redundant manipulator.



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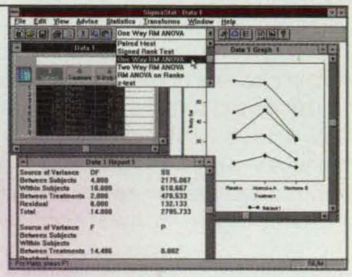

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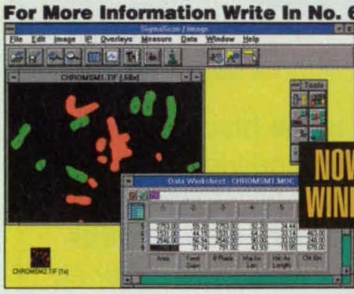

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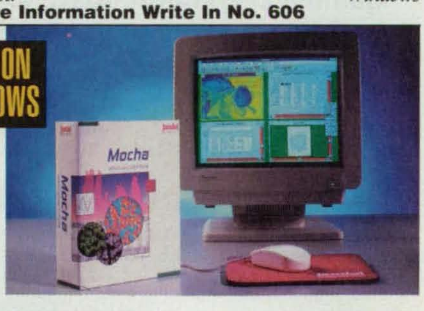


Maximizing Performance of a Telerobot With Minimal Software

Software modules that control various behaviors are activated by sets of parameters.

NASA's Jet Propulsion Laboratory, Pasadena, California

The control software system of an experimental seven-degree-of-freedom telerobot is designed to elicit maximum performance from a minimal, fixed-software computer at the remote robot site. The system includes multiple control modules, each of which provides parameter-driven control of a specified aspect of the behavior of the telerobot. The software system runs in the Ada language on multiple 68020 processors or potentially on a single central processing unit. Conceived for use in outer space, the system may also prove useful in underwater construction and inspection, in handling of materials in nuclear facilities, and in cleaning up hazardous materials.

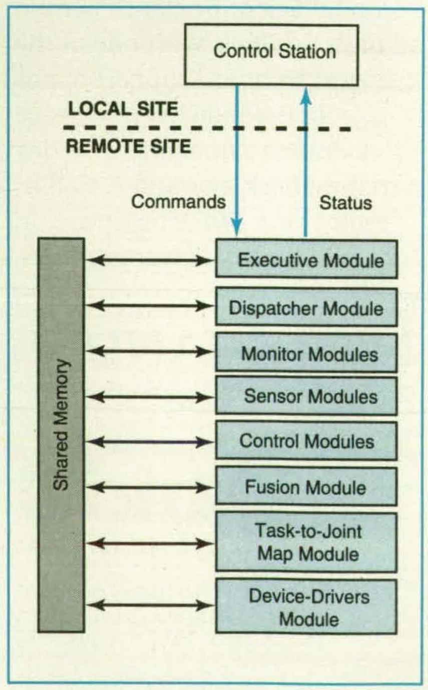
This control software system makes several unique behaviors available simultaneously. These behaviors include force control, generation of trajectories, and avoiding collisions. An important part of the system is a command interpreter, which is essentially a robot language that has limited branching capability but enables concurrent control from several control modules. The permutations of the control-module behaviors are then available to the local site (the control station). The fixed software system can thus provide a wide range of controlled robotic behavior.

Each module communicates with the rest of the system through shared memory (see figure). The modules operate asynchronously, except that one of them — the dispatcher module — coordinates the interactions among the other modules by modifying command and state parameters in the shared memory. The dispatcher module transitions the system between commands in a command sequence and into reflex commands. The other modules and their functions include the following:

The executive module places new task commands from the local site into command queues at the remote site and returns status signals and data to the local site.

- The monitor modules monitor the statuses of execution of tasks and indicates to the dispatcher when an event (e.g., reaching a limiting force or position) has occurred.
- The sensor modules process the outputs of such sensors as angle resolvers, potentiometers, force and torque sensors, proximity sensors, and vision subsystems. Sensor modules generate such data as distances to joint limits and distances to collisions between objects based upon geometric models.
- The control modules generate task-level control signals according to the parametric specification of the task and sensory data.
- The fusion module combines the commands from the various control modules according to the parametric specification of the task.
- The task-to-joint map module maps the task-space command of the fusion module to the actuator space of the robotic manipulator.
- The device-drivers module communicates with the system hardware, sending and receiving commands and indications of status. It also performs hardware-specific computations.

This work was done by Paul G. Backes, Mark K. Long, and Robert D. Steele of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 84*** *on the TSP Request Card. NPO-18745*



Semi-Independent Modules Communicate through a shared memory. The executive module receives commands from the local site control station and returns status signals from the remote site to the local site.

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Dual-Arm Generalized Compliant Motion With Shared Control

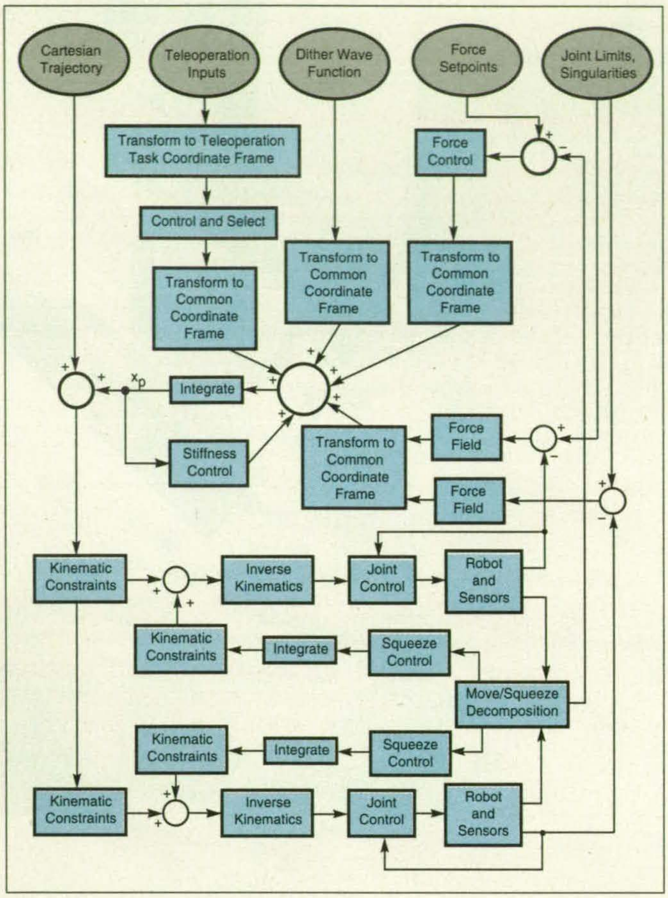
A unified control scheme provides for cooperative dual-arm tasks.

NASA's Jet Propulsion Laboratory, Pasadena, California

The Dual-Arm Generalized Compliant Motion (DAGCM) primitive is a computer program that implements an improved unified control scheme for two manipulator arms cooperating in a task in which they both grasp the same object. The DAGCM primitive provides capabilities for autonomous, teleoperation, and shared control of two robot arms. It unifies cooperative dual-arm control with multi-sensor-based task control and makes the complete task-control capability available to a higher-level task-planning computer system via a large set of input parameters that are used to describe the desired force and position trajectories to be followed by the manipulator arms. Some of the concepts on which the DAGCM primitive are based were discussed in "A Generalized-Compliant-Motion Primitive" (NPO-18134), *NASA Tech Briefs*, Vol. 17, No. 9 (September, 1993), page 132.

Two or more arms holding an object can apply both forces that cause the object to move and forces that build up within the object but do not cause it to move: the former are called "external" or "move" forces, while the latter are called "internal" or "squeeze" forces. The DAGCM primitive decomposes the forces sensed at the wrists of the two manipulators into move and squeeze forces, which it then controls separately. The desired contact interaction between the held object and its environment is specified via contact-force-control parameters in the move subspace; the desired internal forces in the held object are specified via force-control parameters in the squeeze subspace.

The DAGCM primitive uses the generalized-compliant-motion concept to control the motion of the held object on the basis of a specified trajectory of the object in Cartesian coordinates, the control of the move forces from the move/ squeeze decomposition, and the outputs of several sensors in addition to the force sensors on the wrists. As explained in more detail in the mentioned prior article in *NASA Tech Briefs*, the generalized-compliant-motion concept provides for (among other things) multiple-sensor-based control for execution of tasks. The sensors can be either real (e.g., force and torque sensors) or virtual (e.g., a computed distance to collision). Each sensor is provided an individual task space for control, and the resulting motion commanded by each sensor is merged in the common coordinate frame in which the actual position of the held object is measured (see figure).

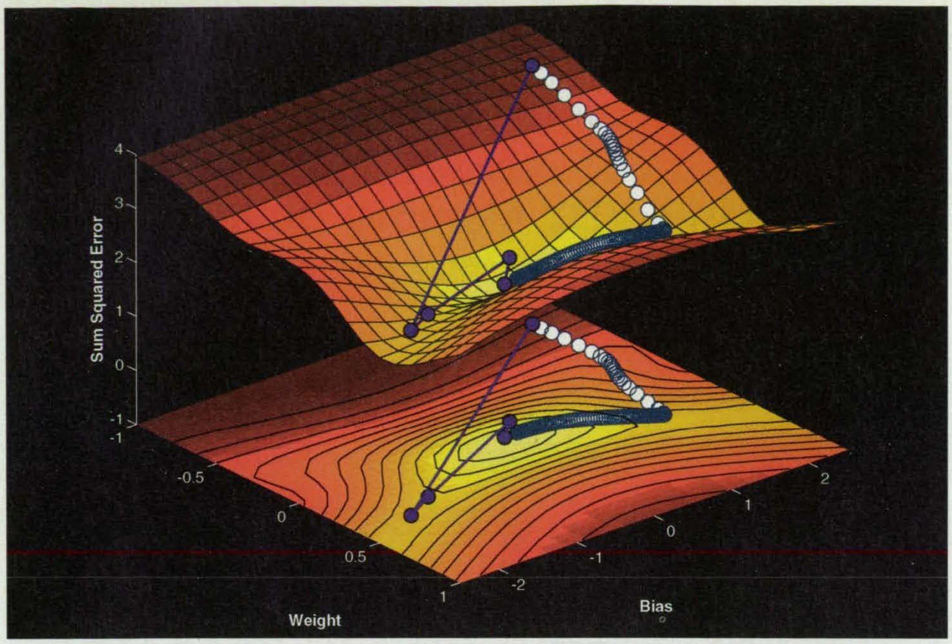


The **Dual-Arm Generalized Compliant Motion Primitive** implements a unified control scheme, shown here schematically, for two manipulator arms grasping and moving the same object.

One of the outstanding features of the DAGCM primitive is that it can implement shared control, which merges teleoperation and autonomous control in real time during the execution of a task. Shared control can take any of several forms. One of them is compliant teleoperation, in which an operator controls the motion of the object (e.g., by use of a single hand controller) and the autonomous control subsystem controls the move and squeeze forces. Another form of shared control is partitioned shared control, in which some degrees of freedom in the task space are controlled by the operator with a hand controller, while the other degrees of freedom are controlled by the autonomous system. In the DAGCM primitive, shared control is specified via input parameters.

This work was done by Paul G. Backes of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 106*** *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, NASA Resident Office– JPL [see page 20]. Refer to NPO-18738.



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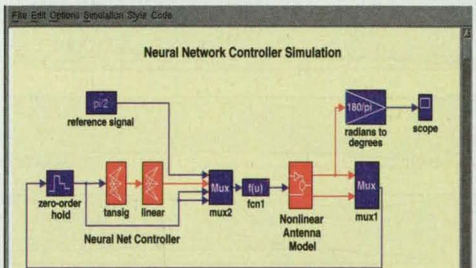

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Partial-Thickness Grooves in a VBL Memory Device

Bias magnetic fields can be tailored to match those needed elsewhere in the device.

NASA's Jet Propulsion Laboratory, Pasadena, California

Grooves through part of the thickness of the magnetic garnet storage layer of a vertical-Bloch-line (VBL) memory device can be used to confine magnetic bubble and stripe domains in the desired storage areas. The VBL-memory concept was described in "Vertical-Bloch-Line Memory" (NPO-18467), *NASA Tech Briefs*, Vol. 17, No. 6 (June 1993), page 42. It is desirable to use partial-thickness grooves (as distinguished from total-thickness grooves) in that the depths and widths of the grooves and the widths of the storage areas between them can be chosen to tailor the ranges of the bias magnetic fields in those areas to match the ranges of bias fields needed elsewhere in the device.

Figure 1 shows the layout of partial-thickness grooves intended to confine magnetic bubbles in a major-line storage area and magnetic stripes in adjacent minor-loop storage areas of an experimental VBL device. The grooves were defined by implantation of 80-keV Na^{+} ions through a mask in a magnetic garnet layer of composition $(YBiGdHoCa)_3(FeGeSi)_5O_{12}$ that was deposited to a thickness of 2.26 μm on a substrate of $Gd_3Ga_5O_{12}$. The minor-loop grooves were etched to a depth of 10 percent of thickness of the garnet layer; a second masked implantation and etch were performed in the major-line grooves to increase the depth to 20 percent.

The magnetic-field responses — that is, the structures of the magnetic domains — in the device were measured and simulated at various applied (bias) magnetic fields to determine the stability margins and thus the ranges of these fields. The simulations were based on the assumption that a uniform, unichiral stripe domain can be represented by a sequence of wall points, the motion of which is governed by the Landau–Lifschitz–Gilbert equation, subject to the applied field(s), demagnetizing field(s), and wall pressure, and subject to a linear mobility that is, in turn, subject to coercivity and wall saturation velocity.

The measured and simulated domain structures were found to agree substantially. Figure 2 shows simulated domain structures in a minor-loop groove. A bubble domain is placed in the groove at a bias field of 190 Oe, which is less than the

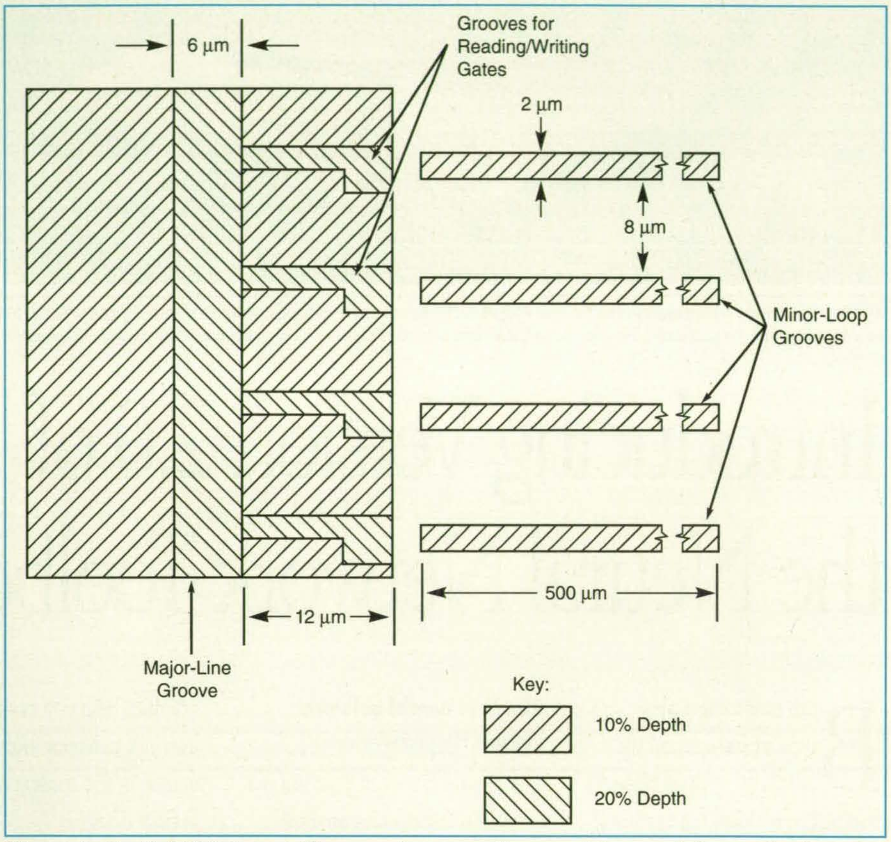

Figure 1. **Partial-Thickness Grooves** in magnetic garnet layers define major-line and minor-loop storage areas.

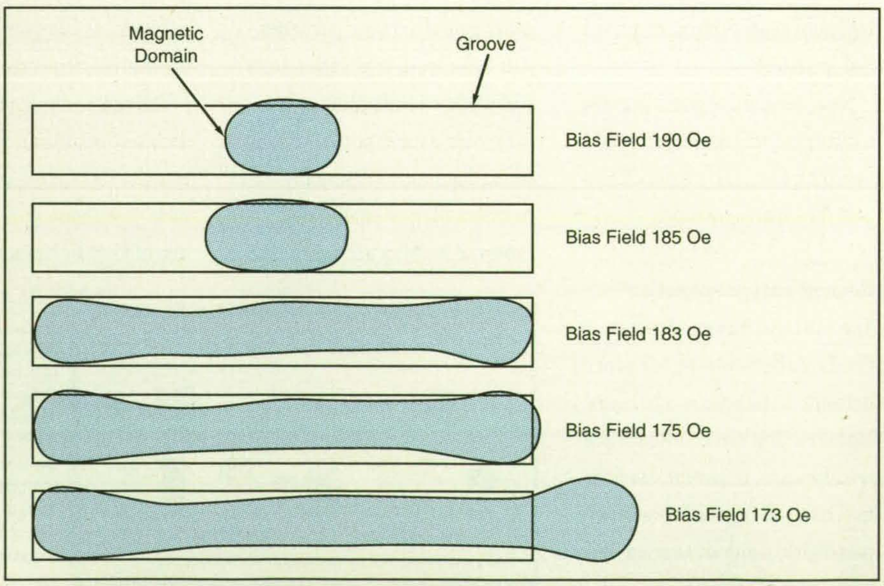

Figure 2. **Shapes of Magnetic Bubble and Stripe Domains** in a minor-loop groove were simulated at five different bias fields.

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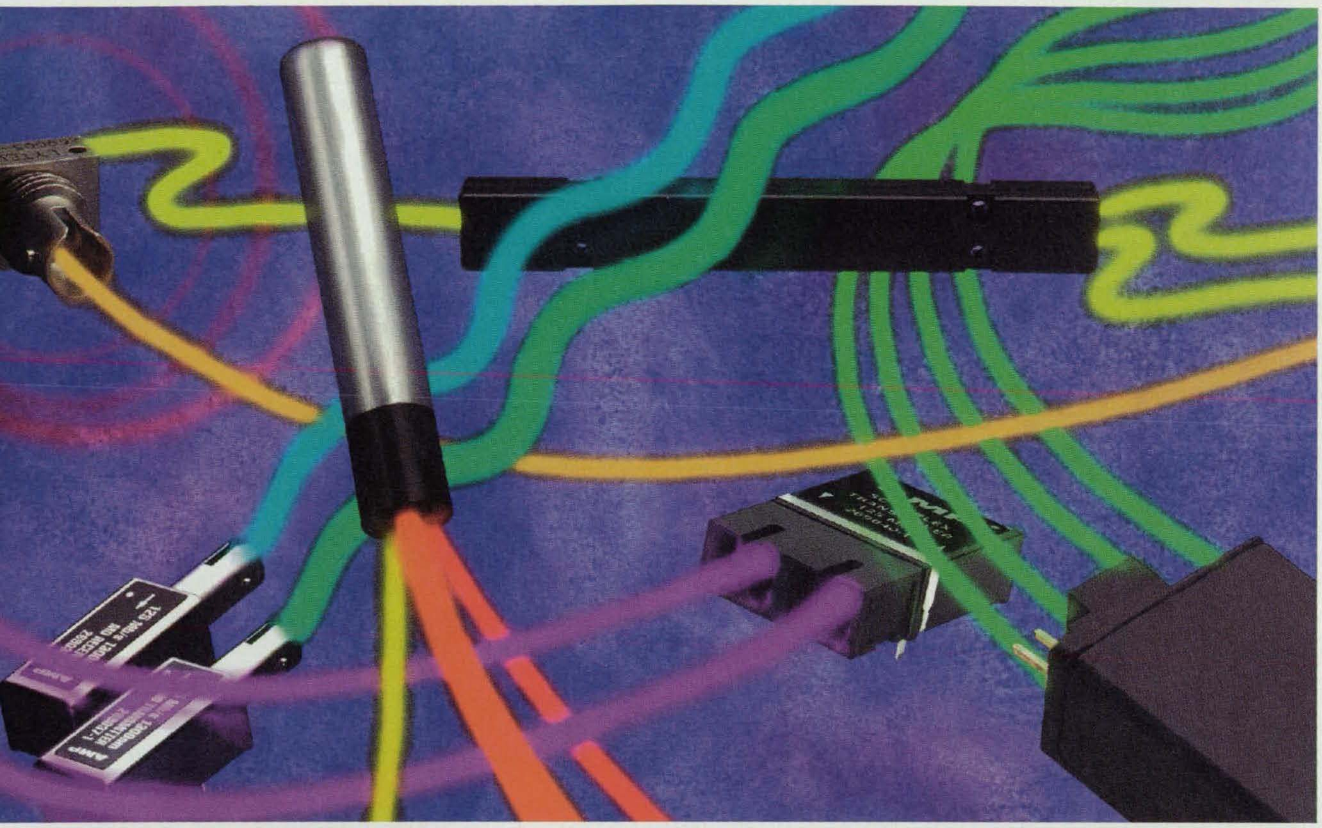

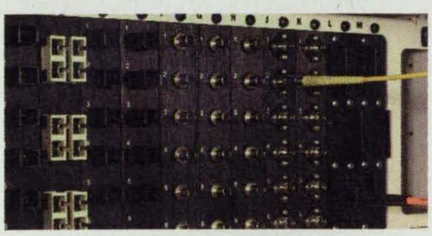

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bubble collapse field. The bias field is decreased in steps, and the bubble domain grows into a stable stripe domain. Eventually, the stripe domain runs out of the groove as the field decreases to 173 Oe. Thus, the range of bias fields that yield stable confinement is about 10 percent of the nominal value, the high-field stability limit is characterized by the recession of the domains into elongated dumbbells and eventually bubbles, and the low-field stability limit is characterized by the runout of the stripe domain from the groove.

The minor-loop stability margins of this device match those of the major line more closely than do those of prior VBL devices. However, deeper partial-thickness grooves may be needed to obtain a better match. Finally, the simulations show that magnetostriction, treated as an effective magnetic field, induces shifts in the stability range of bias fields. However, measurement data indicate that magnetostatic effects predominate over magnetostrictive effects.

This work was done by Romney R. Katti, Jiin-Chuan Wu, and Henry L. Stadler of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 50*** *on the TSP Request Card.*

NPO-18749

Monolithic Three-Stage 32-GHz Power Amplifier

Moderate power and relatively high efficiency are achieved in a small package.

Lewis Research Center, Cleveland, Ohio

Figure 1 shows a three-stage monolithic integrated-circuit power amplifier that operates at frequencies around 32 GHz. It is designed for use aboard a communication satellite and is also suitable for terrestrial applications in which moderate power and high efficiency are needed. At 32 GHz, its efficiency can be as high as 30.1 percent, with output power of 180 mW and gain of 23 dB. The efficiency of the best previous multistage amplifier operating at nearby frequencies (in the K_a band) was only 18 percent.

The dimensions of the amplifier are only 2.38 by 1.04 by 0.10 mm. Each stage of amplification includes an AlGaAs/InGaAs/GaAs heterostructure field-effect transistor (HFET). The widths of the gates in the three transistors are 50 μm, 100 μm, and 250 μm, respectively, and all three gates are 0.20 μm long. The drain- and gate-bias circuits are integrated onto the circuit chip. The input and output circuits are matched to 50 Ω.

Each transistor (see Figure 2) includes a doped heterojunction that consists of a layer of AlGaAs 400 Å thick and a layer of $In_{0.2}Ga_{0.8}As$ 120 Å thick. These layers, doped at 2×10^{18} cm^{-3}, are grown on a buffer layer of undoped GaAs. A heavily doped contact layer of GaAs is grown on top of the AlGaAs layer. One of the advantages of this structure is that it can be grown easily by molecular-beam epitaxy. It offers high transconductance, high maximum current, and reasonably high breakdown voltage while offering state-of-the-art performance at frequencies around 32 GHz.

This work was done by Paul Saunier and Hua-Quen Tserng of Texas Instruments and Edward Haugland of **Lewis Research Center**. *For further information,* ***write in 47*** *on the TSP Request Card.*
LEW-15525

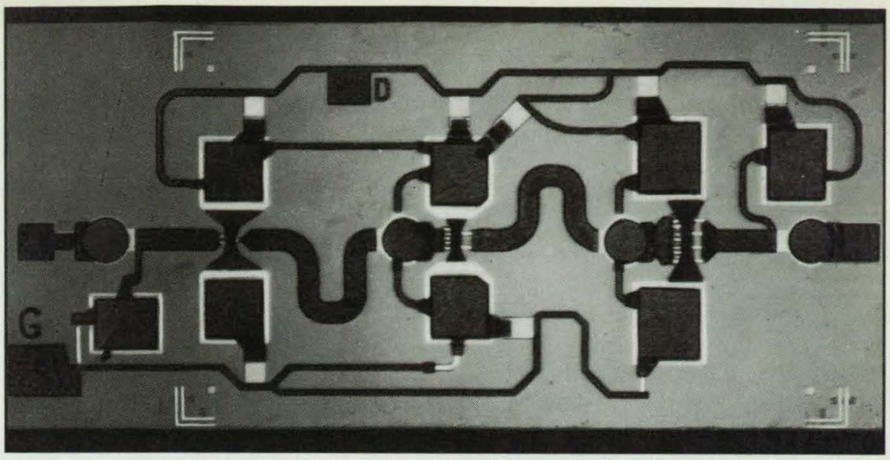

Figure 1. The **Monolithic Three-Stage 32-GHz Power Amplifier** is compact and offers

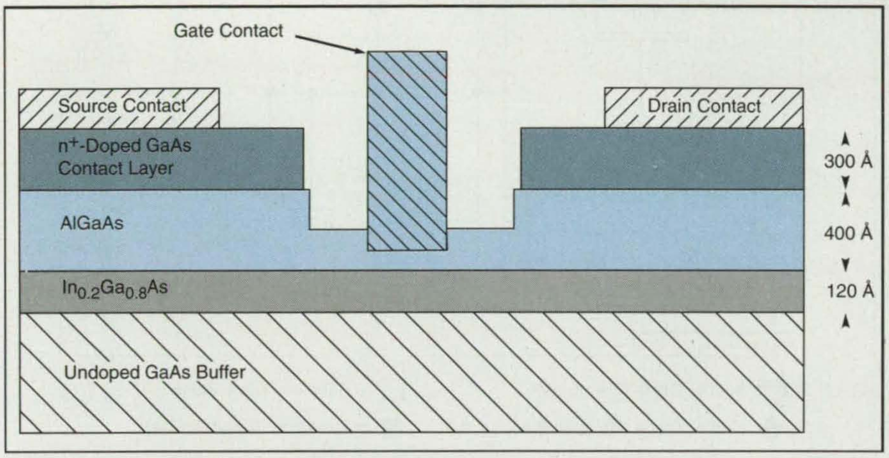

Figure 2. The **Structure of the Transistor** in each stage of the amplifier provides for ease of fabrication and reliability of gate access.

Making a D-Latch Sensitive to α Particles

The sensitized D-latch is used to study single-event upsets.

NASA's Jet Propulsion Laboratory, Pasadena, California

A standard complementary metal oxide/semiconductor (CMOS) D-latch integrated circuit can be modified to increase its susceptibility to single-event upsets (SEU's) (changes in logic state) caused by impacts of energetic α particles. The modified D-latch is suitable for use in relatively inexpensive bench-scale SEU tests of itself and of related integrated circuits like static random-access memories.

The modification is what makes bench-scale testing possible. Typical unmodified D-latches are designed to be relatively invulnerable to SEU, even in the presence of cosmic rays. Heretofore, to measure the relatively low SEU sensitivities of these circuits, it has been necessary to expose them to heavy ions in high-energy particle accelerators. In the bench test, the modified, sensitized latch is exposed to α particles from a 4.6-μCi ^{241}Am source.

As shown in Figure 1, the modification consists in disconnecting the pullup metal oxide/semiconductor field-effect transistor (MOSFET) from the main supply potential V_{DD} and connecting it to V_{off}, which is a variable offset potential. If the amount of charge that the ionization trail left by an energetic ion deposits in a sensitive junction exceeds a critical charge, Q_c, then a SEU occurs. The critical charge can be decreased and the sensitivity to SEU correspondingly increased by lowering V_{off}. The measurements of the SEU rate as a function of V_{off} (see Figure 2) can be extrapolated to estimate the SEU rate and other measures of upsettability at V_{off} = V_{DD} = 5 V (the normal supply voltage).

This work was done by Martin G. Buehler, Brent R. Blaes, and Robert H. Nixon of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 79*** *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
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Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Refer to NPO-18614, volume and number of this NASA Tech Briefs *issue, and the page number.*

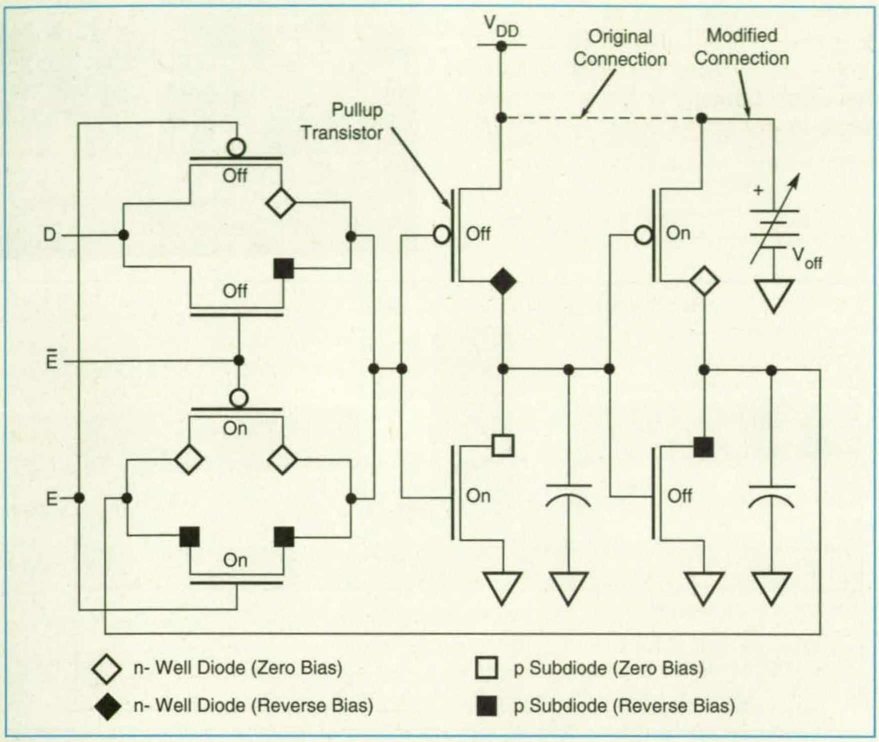

Figure 1. This **D-Latch** is made more sensitive to α particles by disconnecting the pullup MOSFET from V_{DD} and connecting it to V_{off}, which is less than V_{DD}. The diodes marked as solid squares are most susceptible to SEU because they sit on a p-doped substrate, where plasma tracks induced by a particles are not truncated.

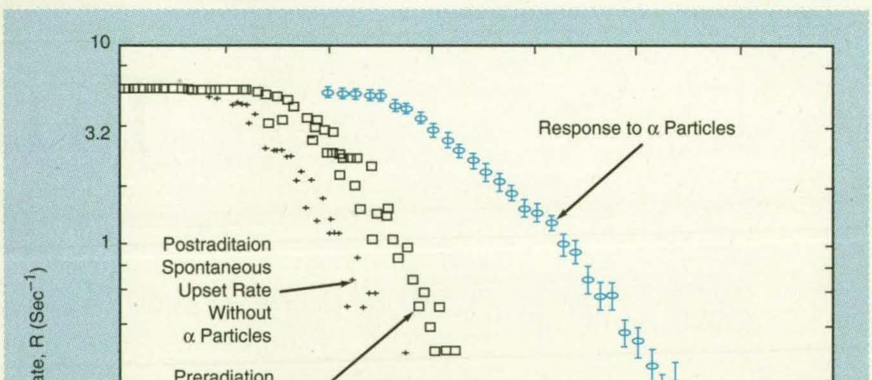

Figure 2. The **Upset Rate of the D-Latch** was measured at various levels of V_{off} during exposure to a ^{241}Am source of a particles. The data were taken at 5-mV intervals. Error bars represent 10 samples with 10-second exposure times.

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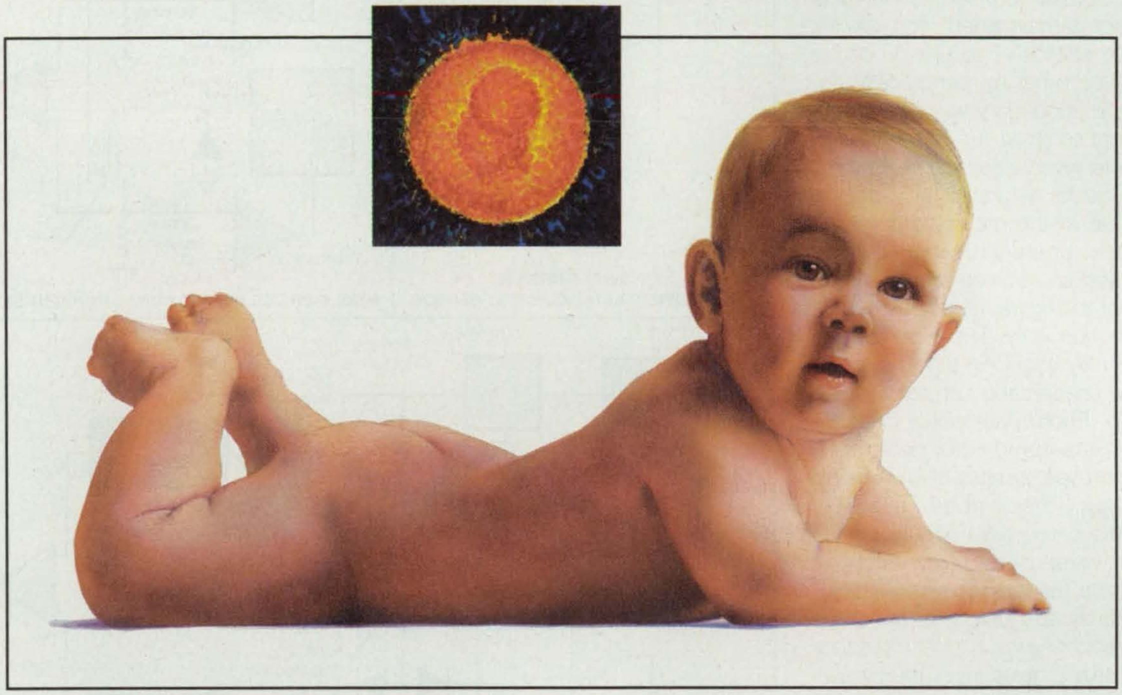

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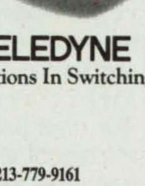

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Three Magnetic Direct-Current Sensors

Unidirectional and bidirectional versions have been demonstrated.

Lewis Research Center, Cleveland, Ohio

The figure illustrates three circuits that sense direct currents magnetically, via transformer coupling, rather than via direct electrical contact. In each of these circuits as in some magnetic direct-current-sensing circuits described in previous articles in *NASA Tech Briefs*, (1) the current to be measured flows in a single- or few-turn primary winding on a toroidal transformer core and (2) the transformer effect is maintained (equivalently, the adverse effects of saturation of the core are overcome) by periodically applying, to the secondary winding, a voltage sufficient to reset the magnetic flux in the core to reverse saturation. Reverse saturation means saturation at a polarity opposite that of the magnetic flux generated by the current to be measured.

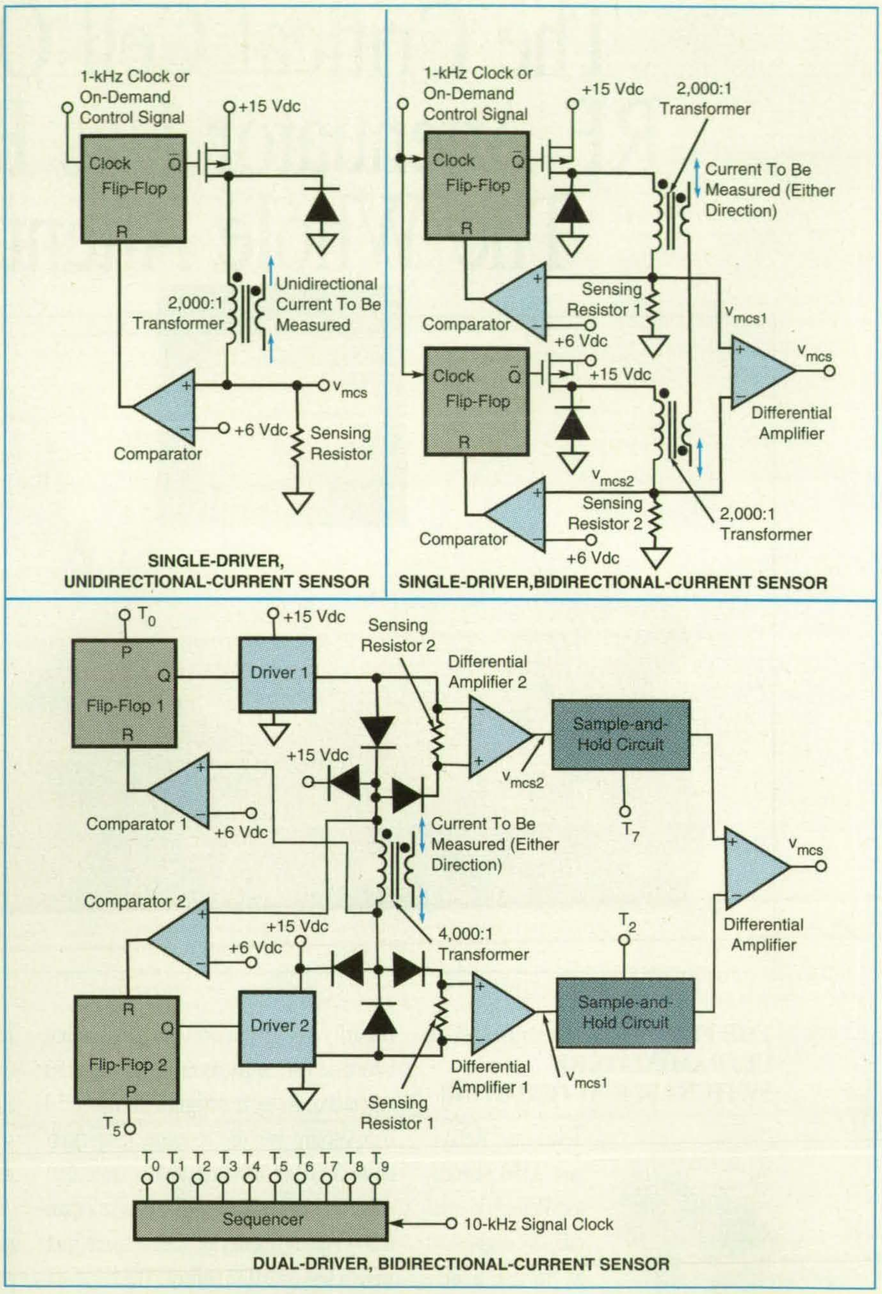
The simplest of the three circuits, shown at the top of the figure, measures current in one direction only. The reset pulses are initiated by applying a 1-kHz clock signal or an on-demand control signal to the flip-flop. Each reset pulse is terminated when the comparator determines that the voltage across the sensing resistor, v_{mcs}, rises above a preset value (in this case, 6 V), signifying the onset of reverse saturation. Allowing sufficient time for the reset-pulse transients to decay and before forward saturation is reached, v_{mcs} is sampled for 10 μs to obtain a measure of the primary current to be measured (v_{mcs} is proportional to this current before saturation is reached).

Two circuits like the one shown above can be combined into a circuit that measures current in either direction, as shown in the middle of the figure. In this case, the current flows in opposite senses in the primary transformer windings of the two component circuits, and the voltages across the two sensing resistors (v_{mcs1} and v_{mcs2}) are combined via a comparator to obtain a single output voltage, v_{mcs}, proportional in both magnitude and sign to the current to be measured.

The circuit shown at the bottom of the figure contains a single transformer core but includes two flux-reset drivers and two sensing resistors and can measure current in either direction. In this circuit, the 1-ms operating cycle is divided into equal intervals, and the various functions are initiated by use of a 10-kHz clock and a 10-output sequencer. The reset pulses are initiated at the beginnings of alternate half cycles. Each reset pulse is terminated when the appropriate voltage (v_{mcs1} or v_{mcs2}) rises above 6 V, indicating saturation. The voltage across each sensing resistor (v_{mcs1} or v_{mcs2}) is sampled at a designated nonsaturation time during its respective reset cycle.

These circuits are examples of a class of magnetic current-measuring circuits that consume little power. Tests have shown that in comparison with Hall-effect magnetic current sensors, these circuits are about equally accurate but are more stable under changes in temperature. Overall, these circuits are more dependable than other magnetic current-sensing circuits are.

This work was done by Craig C. Sullender and David A. Stagg of Rockwell International Corp. for **Lewis Research Center**. *For further information,* ***write in 10*** *on the TSP Request Card. LEW-15173*

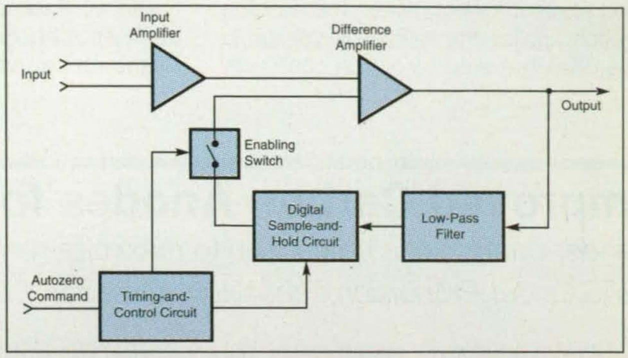


These **Three Direct-Current-Measuring Circuits** are based on magnetic (transformer) coupling, with periodic reset of magnetic flux to reverse saturation. In comparison with other magnetic current-sensing circuits, these offer greater reliability and lower power consumption.

Autozero Unit

This circuit suppresses the dc component of an analog signal without introducing phase shift.

Langley Research Center, Hampton, Virginia



The **Autozero Unit**, shown here in simplified form, subtracts the dc component of the input signal, so that the output contains only the ac component.

An 8-channel signal processor — an autozero unit — suppresses the dc component of an analog voltage signal that varies with time in a complicated way, without introducing phase shift into the ac component. This autozero unit would be installed in an instrumentation system between a signal source and data-acquisition equipment.

Typically, unwanted dc voltage is removed by capacitively coupling the signal from one circuit to another. However, capacitive coupling blocks both desired and undesired dc voltage, and introduces phase shift, frequently complicating time-domain analysis of signal data and making such analysis impractical. Upon command, the autozero unit removes the dc component that exists in the signal at the time of the command, but passes the ac and dc components of the ensuing signal. An autozero command can be initiated from the front panel of the autozero unit or remotely from an external source.

The autozero unit has an accurate fixed gain of 1 and passes input signals in the range of ±10 V at frequencies of 0 to 50 kHz. To improve suppression resolution, a maximum dc suppression of 3.0 V or 0.3 V is selected with a front-panel switch for each channel. The autozero function can be disabled on all channels simultaneously with a front-panel switch, thereby allowing data signals to pass unaffected through the autozero unit. Other features include high impedance, differential inputs to match various signal sources, a front-panel selector switch to enable monitoring of the output of any channel, and front-panel light-emitting diodes to provide a visual indication of the operational status of the autozero unit.

At the core of the dc-suppression process of the autozero unit is a digitally implemented sample-and-hold circuit (see figure), which samples and stores the dc voltage level to be subtracted from the incoming signal. Two high-quality, microcircuit instrumentation amplifiers conform to excellent data-signal-throughput specifications. An autozero command to a timing-and-control circuit within the autozero unit initiates the dc-suppression process. The timing-and-control circuit synchronizes sampling of the incoming signal and storage of the dc level with the operation of an enabling switch. A low-pass filter extracts the dc component from the complicated incoming analog signal. The digital sample-and-hold circuit reads the extracted dc voltage level and stores it for long times. The enabling switch applies the stored dc voltage to the difference amplifier, which continually subtracts this dc voltage level from the incoming analog signal until another autozero command is issued.

This work was done by William C. White of Wyle Laboratories for **Langley Research Center.** *For further information,* ***write in 24*** *on the TSP Request Card.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14882.

Improved Carbon Anodes for Rechargeable Lithium Cells

Binder content can be chosen to maximize reversible lithium capacity.

NASA's Jet Propulsion Laboratory, Pasadena, California

Carbon anodes for rechargeable lithium cells have been improved by choosing binder contents and fabrication conditions to achieve maximum porosity, uniform loading, and maximum reversible lithium capacity. In addition, it has been demonstrated that stacking electrodes under pressure during assembly of cells increases the cyclability of lithium. Rechargeable, high-energy-density lithium cells that contain these improved carbon anodes may find use in spacecraft, military, communications, automotive, and other demanding applications.

Because of its low equivalent weight, low voltage vs. Li, and stability toward electrolytes, carbon is being studied as an anode material alternative to Li in rechargeable Li cells; as an anode material, Li is somewhat disadvantageous in that it is highly reactive toward electrolytes, and after repeated cycling, cells that contain lithium anodes become unsafe because lithium dendrites form, resulting in short-circuiting of the cells.

The successful replacement of Li by C in these applications is not trivial. Although carbon powder can be compacted at high temperature and pressure, the sintering makes the electrode less porous, thereby reducing the achievable rates of charge and discharge and the capacity for intercalation of Li. Consequently, a suitable composition and quantity of binder have been sought to enable the fabrication of carbon electrodes at low temperature; too much binder would result in smaller specific energy, charge-rate, discharge-rate, and intercalation capabilities, whereas insufficient binder would not hold the carbon particles together.

The electrochemical intercalation of Li into carbon electrodes was studied in experiments by use of the following cell configuration: (–) Li/1.5M $LiAsF_6$ in 10 percent EC + 90 percent 2-methyl tetrahydrofuran/Li_xC (+). The fabrication of electrodes for these experiments began with mixing of graphite powder with a 0.5 volume percent solution of ethylene propylene diene monomer (EPDM) binder in cyclohexane until a uniform slurry was obtained. For each electrode, the slurry was painted evenly on both sides of a nickel grid (which served as a mechan-

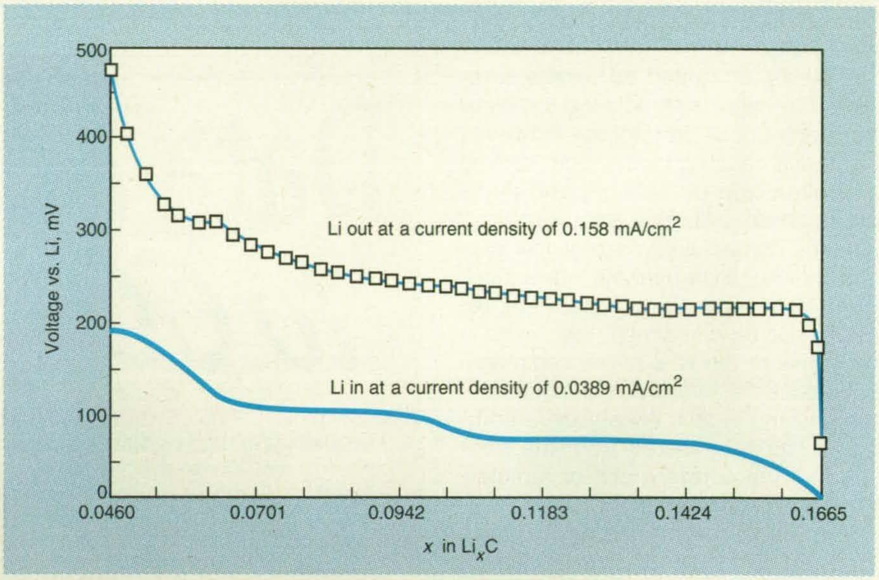


Figure 1. **Electrochemical Intercalation and Deintercalation** of Li in a graphite electrode of optimal binder content were measured in an electrochemical cell.

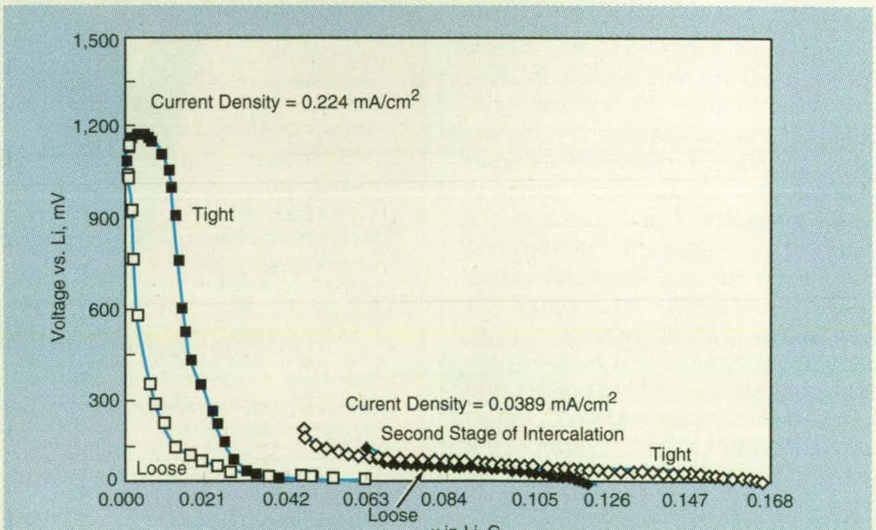


Figure 2. The **Effect of Electrode-Stacking Pressure** on the performance of a cell is illustrated. The cell has a charge capacity of 1 A·h, and the composition of the carbon electrode is the optimal 0.5 weight percent EPDM binder with 99.5 weight percent graphite powder.

ical support and current collector of the electrode) and was then evaporated to dryness. The electrodes were then pressed between stainless steel plates at a pressure of about 450 lb/in.^{2} (3.1 MPa). The painting, drying, and pressing procedures were repeated until the desired loading was achieved. Typically, the carbon electrode material had covered the nickel support to a thickness of 10 to 15 mils (0.25 to 0.38 mm), with a mass loading of 10 to 15 mg/cm^2.

The electrodes that performed best in the electrochemical experiments had compositions of 0.5 volume percent EPDM and 99.5 volume percent C. Li was intercalated into carbon in two stages, approaching the theoretical maximum Li content LiC_6. As shown in Figure 1, this material exhibits high Li reversibility when the x in Li_xC is in the range from 0.0460 to 0.1665; this range corresponds to the second stage of intercalation of Li in C.

The cyclability of lithium was found to depend strongly on electrode-stacking pressure. This type of information is vital to the design of rechargeable Li cells because the nature of the physical containment of the anode determines the mechanical pressure exerted on it. Figure 2 illustrates selected performance characteristics of an electrode stacked at two different pressures, indicating that performance in the relatively tightly packed cell is superior at both the first and the second stages of intercalation.

This work was done by Chen-Kuo Huang, Subbarao Surampudi, Alan Attia, and Gerald Halpert of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 75*** *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

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Refer to NPO-18823, volume and number of this NASA Tech Briefs *issue, and the page number.*

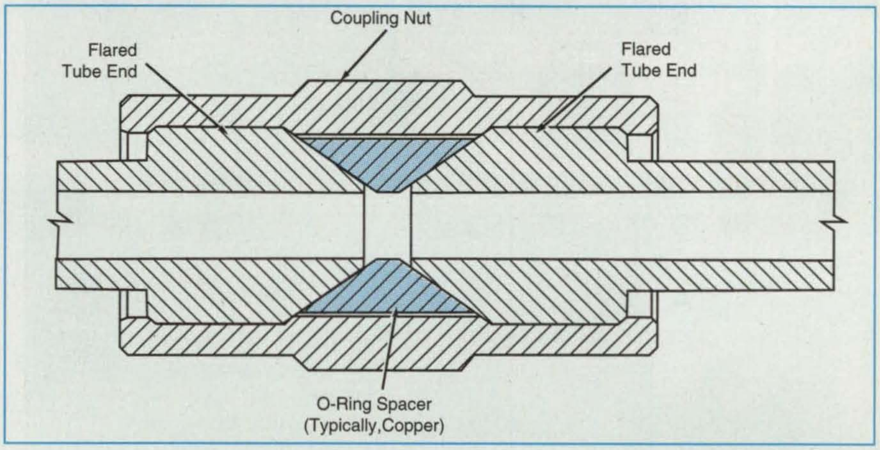
Self-Sealing Cryogenic Fitting

Coefficients of thermal expansion and shapes of components are chosen so that cooling causes tightening.

John F. Kennedy Space Center, Florida

A self-sealing fitting for cryogenic tubes remains free of leakage from room temperature to liquid-helium temperature (about 300 K to 5 K), even at an internal pressure as high as 2.7 MPa. The fitting comprises parts made of materials with different coefficients of thermal expansion to prevent leakage gaps from forming as the temperature decreases.

In a conventional fitting that carries a hot fluid, prevention of leakage is not ordinarily a problem; thermal expansion of the mating parts tends to tighten the seal. However, when the same fitting, tightened at room temperature, carries a cold fluid, the parts of the fitting contract differentially, forming gaps. According to one analysis, if a gap increases 50 percent because of a decrease in temperature, the rate of leakage will increase more than 300 percent. Also of course, the rate of leakage is greater if the fluid is under high pressure.



The O-Ring Spacer Contracts More than the tube ends do as the temperature decreases. This greater contraction seals the tube ends more tightly, preventing leakage.

The present self-sealing fitting consists of a coupling nut, two flared tube ends, and a flared O-ring spacer (see figure). The O-ring spacer is made of a metal (for example, copper) that has a coefficient of thermal expansion greater than that of the material of the coupling nut and tube ends [for example, Invar (or equivalent) low-thermal-expansion alloy]. When the spacer contracts during cooling, it clamps the tube ends more tightly, thereby tightening the joint further.

The values of the tube-end flare angle, the radii of the O-ring spacer, and the coefficients of expansion of the two metals must be chosen within certain ranges in an interdependent way. The designers of the fitting have developed tables and plots that express the relationships among these variables.

In a leak test, the fitting was filled with liquid helium at a pressure of 2.71 MPa and held in a vacuum chamber at a temperature between 4.5 and 6.9 K for 5 hours. The vacuum gauges did not detect any leakage in the vacuum. In contrast, a conventional fitting started to leak as its temperature decreased below 205 K. At 77 K, it leaked 1.28×0^{-3} kg/min.

This work was done by Lin Xiang Jia, Wen Lung Chow, and Davood Moslemian of Florida Atlantic University and Gary Lin and Greg Melton of **Kennedy Space Center**. *For further information,* ***write in 81*** *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

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Boca Raton, FL 33431-0991

Refer to KSC-11599, volume and number of this NASA Tech Briefs *issue, and the page number.*

Advanced p-MOSFET Ionizing-Radiation Dosimeter

Threshold voltage would vary with dose, but not with temperature.

NASA's Jet Propulsion Laboratory, Pasadena, California

Figure 1 illustrates a proposed circuit that would yield measurements indicative of the total dose of ionizing radiation. The conceptual design and operation of the circuit are based on measurement of the threshold gate voltage, V_T, of a p-doped-channel metal oxide/semiconductor field-effect transistor (p-MOSFET): V_T changes as radiation-induced electric charge accumulates in the gate oxide.

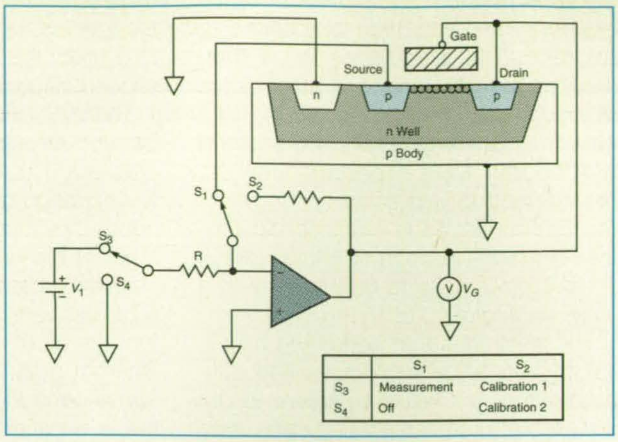

Figure 1. This **Circuit Would Measure the Total Dose** of ionizing radiation in terms of the shift in threshold gate voltage of the p-MOSFET.

The p-MOSFET would be connected into the feedback loop of an operational amplifier for measurement of its gate voltage, V_G (which sometimes does and sometimes does not equal V_T, depending on other voltage and current conditions). Switch positions S_1 through S_4 would be used to set the bias voltages and currents. The effect of accumulated radiation-induced charge would depend on bias conditions: the rate of change of V_T with the dose rate would be greatest — that is, the p-MOSFET would be most sensitive to radiation — in the "off" bias condition. Thus, the p-MOSFET would normally be exposed to radiation in the "off" condition. After exposure, V_T would be determined in the "measurement" (S_1, S_3) bias condition. Two switch settings would provide calibration bias conditions for determination of two radiation-damage coefficients and two temperature coefficients: the rates of change of threshold voltage and transconductance with radiation dose (a ^{60}Co radiation source would be used in this calibration) and the rates of change of threshold voltage and transconductance with temperature.

The structure of the p-MOSFET would be based on a virtual-ground principle to eliminate a current path along which accumulated radiation-induced charge would otherwise leak slowly from the gate region and thereby degrade the radiation measurement. For this purpose, the p-MOSFET would have an "edgeless" configuration, in which the source would surround the drain. In addition, all junctions except the drain would be held at zero bias voltage. The operational amplifier would hold the source at zero bias by providing a drain current of $I_D = V_1/R$. Operation in the saturation region of the current-vs.-voltage characteristic would be ensured by connecting the source to the drain, and the drain voltage would thus be set at V_G by the operational amplifier.

Dosimetry via the shift in threshold voltage of a p-MOSFET is influenced by second-order changes of transconductance and threshold voltage with temperature. It is necessary to compensate for or prevent these changes to determine radiation doses accurately. In this circuit, the effect of variation in temperature would be suppressed by setting the drain-current bias in the "measurement" condition at the temperature-independent point indicated in Figure 2. With this bias setting, the charge in gate voltage indicative of the dose would depend on the dose but not on temperature.

This work was done by Martin G. Buehler and Brent R. Blaes of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 78*** *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

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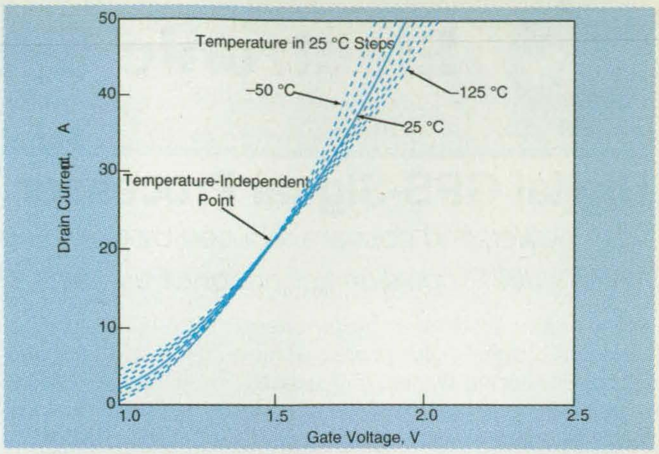


Figure 2. The **Drain Current Would Be Set** at the temperature-independent point to increase accuracy in determination of the radiation dose.

Electronic Systems

Digital GPS-Signal Processor With P-Code/No-P-Code Option

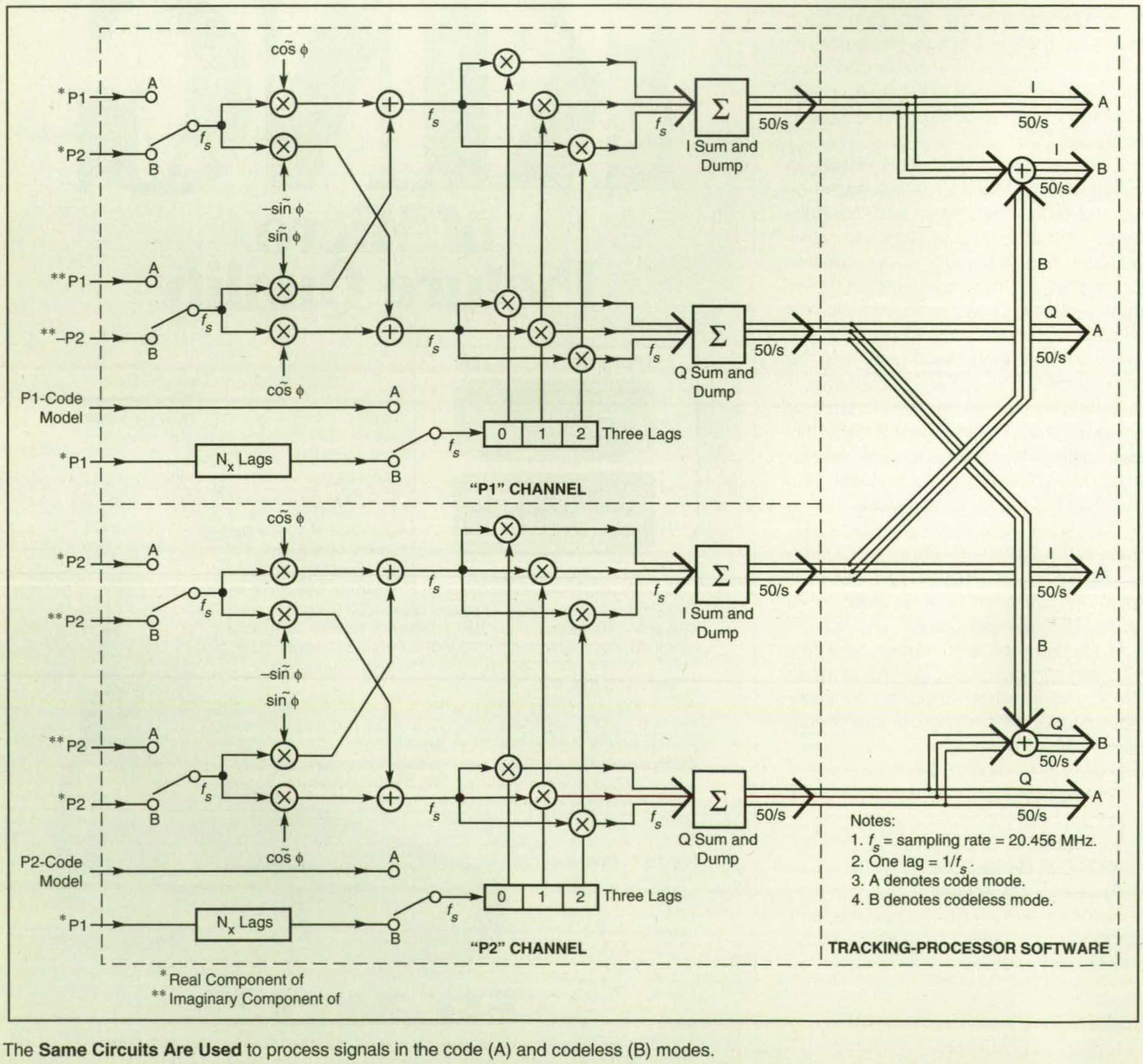
Size, power, and cost are reduced by exploiting commonality.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure illustrates the functional blocks of a digital signal processor for a Global Positioning System (GPS) receiver that can be set to operate in a "code" mode when the P code is known, or in a "codeless" mode when the P code is not known. (The P code is a pseudorandom-noise code, transmitted via phase modulation; knowledge of the P code is necessary to obtain full accuracy.) In the codeless mode, this processor performs full-quadrature processing, which results in a signal-to-noise ratio (SNR) 6 dB greater than the SNR's of processors that do not perform at full quadrature.

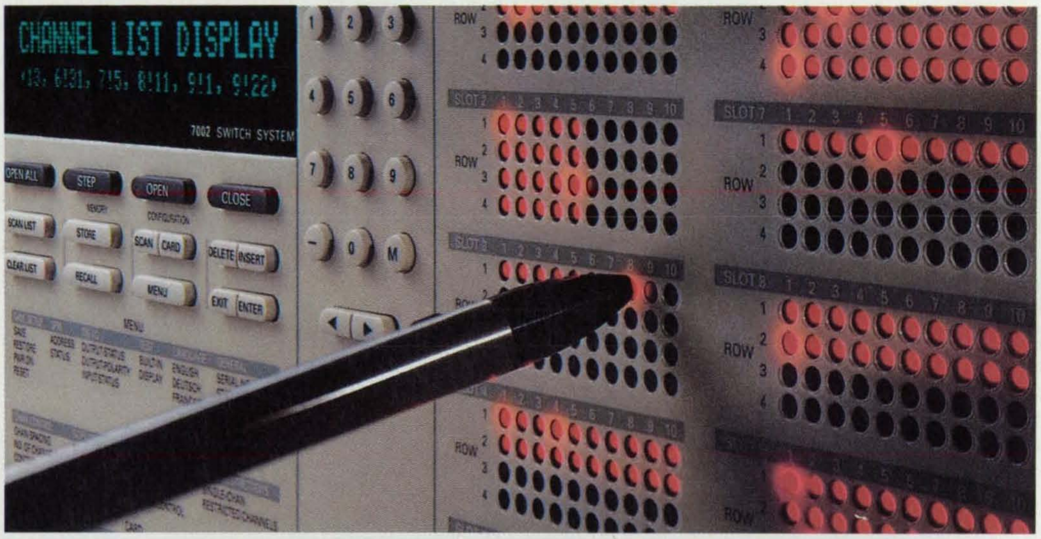
The typical older GPS-signal processor operates either in the code mode (only) or in the codeless mode (only) or else contains separate circuits for the two modes. In contrast, the design of this processor exploits the common aspects of code-mode and codeless-mode processing, using mostly the same circuitry to perform operations in both modes. As a result, this processor is smaller, costs less, and can consume less power than a GPS-signal processor with separate circuitry for the two modes.

The GPS signals are transmitted at two L-Band carrier frequencies called "L1" and "L2," with P-code modulations called "P1" and "P2," respectively. This processor is designed to perform full-quadra-



The **Same Circuits Are Used** to process signals in the code (A) and codeless (B) modes.

Want to switch from femtoamps to amps, nanovolts to kilovolts, DC to 500MHz?



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	Model 7001	Model 7002
Density (2-pole)	Up to 80 channels	Up to 400 channels
Current Range	10fA to 5A	10fA to 5A
Voltage Range	30nV to 1.3kV	30nV to 1.3kV
Ohms Range	nΩ to TΩ	nΩ to TΩ
Frequency Range	DC to 500 MHz	DC to 500 MHz
Scanning Speed	Up to 225 ch/sec	Up to 400 ch/sec
Card Slots	2	10
Main Display	VFD	VFD
Channel Display	VFD	LED Grid
Memory Locations	100	500
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ture cross-correlation of the L1 and L2 signals, in the codeless mode. With proper selection of the inputs, almost all of the cross-correlation operations can be performed by circuitry developed previously for full-quadrature code-mode processing. These operations are counterrotation of the carrier-signal phasors, lagging of the L1 signal with respect to the L2 signal correlation, and accumulation.

Three changes must be made in the previously developed circuitry to provide for operation in both modes. Two of these changes are the addition of a set of input-selecting switches and the addition of a delay line controlled by the tracking processor, which is the software that completes the tracking loops. The third major change consists of additions to the tracking-processor software for processing correlation sums and computing phase and delay feedback.

In the code mode, input consists of quadrature baseband samples of the L1 and L2 signals at a sampling rate of 20.456 MHz. In each channel, the input samples are first counterrotated in quadrature on the basis of feedback supplied by the tracking processor, which downconverts the carrier frequency to zero when in lock. This operation involves complex multiplication, and for a given code channel, it produces two in-phase (I) components and two quadrature (Q) components, which are respectively added. Each of the two resulting quadrature components is then sent into three branches, and in each branch it is multiplied by a lagged code-model sample generated on the basis of feedback supplied by the tracking processor. The three lagged code models are identical except for lag steps in units of the sampling period, ($1/20.456$) μs. The three complex products are then accumulated over a correlation interval (e.g., 19 ms). This correlation process is carried out separately for each P channel and produces 12 correlation sums (3 lags ×2 complex components ×2 P channels) in the combined P-channel output. The correlation sums are passed to the tracking processor for analysis and computation of feedback.

In the codeless mode, the L2 complex samples become the signal input for both the "P1" and "P2" channels, while the L1 complex samples are injected where the code-model samples were injected in the code mode. The L1 samples are selected as substitute "code-model" input because the L1 signal undergoes a smaller ionosphere delay than L2 does and therefore generally must be delayed relative to L2 before cross-correlation. In some cases, however, even more compensation for ionosphere delay is needed. The delay line controlled by the tracking processor satisfies the need for additional L1 delay in these cases.

In the codeless mode, two of the four output correlation sums are I components and two are Q components of the cross-correlation between L1 and L2. The two I components and the two Q components are respectively added by the tracking processor.

This work was done by J. Brooks Thomas and Jeffrey M. Srinivasan of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 8*** *on the TSP Request Card.*
NPO-18831

Versatile Dual-Channel Waveform Generator

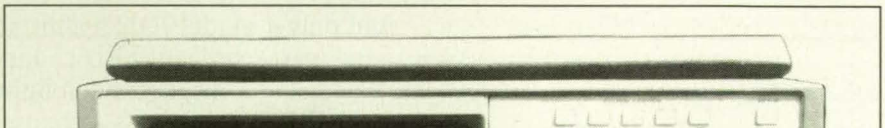
The use of commercial integrated circuits helps keep the cost low.

Lewis Research Center, Cleveland, Ohio

A programmable waveform generator synthesizes two independent waveforms simultaneously at frequencies up to 250 MHz. The waveforms are programmed from a personal computer. The waveforms can be in phase or out of phase with each other.

The direct digital synthesizer has been used to generate in-phase and quadrature chirp signals to test a satellite communication system. It can also generate waveforms with amplitude, frequency, phase, and quadrature amplitude modulation, as well as bipolar phase-shift keying, quadrature phase-shift keying, and quadrature amplitude modulation. When used with a single-sideband modulator, the waveform generator can produce polyphase coding of GHz transmissions for application in modern stealth radio and radar systems. It can also serve as a general-purpose bench-top instrument, replacing separate pulse generators, sine-wave generators, and other function generators.

To keep the cost relatively low (about $10,000 in 1991), the waveform generator is designed to incorporate commercial very-large-scale integrated circuits of two types: a 250-MHz, 40-bit, multitap



This **Waveform Generator** synthesizes two different signals simultaneously, as the upper and lower waveforms (the I and Q baseband components of a chirp signal) on the oscilloscope exemplify. The waveform generator is the module under the oscilloscope.

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shift register and a 250-MHz, multichannel, 8-bit digital-to-analog converter. Two of the shift registers are used in each channel, with taps set at every 8th bit. Data are loaded in parallel into the registers, 8 bytes at a time every 32 nanoseconds, leaving 7 nanoseconds beyond the access time of a random-access memory for delays and margin. The data bits are interleaved so that each byte appears in succession at the eight taps every time the register is clocked at 250 MHz.

The waveform generator contains 16 kilobytes of internal memory per channel; this capacity can be expanded to 32 kilobytes per channel. In each channel, a maximum output signal of ±1 volt is fed into a 50-ohm load. Although resolution is limited to 8-bit quantization (48 dB), programmable attenuators in each channel make it possible to generate signals as small as −100 dBm in 10-dB steps. Operation is governed by BASIC source code that enables any user equipped with a suitable personal computer to specify waveforms. The user can also modify the source code to satisfy special needs.

Other potential applications include the simulation of Doppler waveforms for radar, and of video signals for testing color displays and computer monitors. With the eventual substitution of gallium arsenide integrated circuits for its present silicon integrated circuits, the instrument will be able to generate waveforms with 14-bit precision and sample rates as high as 2 GHz.

This work was done by Edward J. Staples, Sen Lie, and Michael Ching of Amerasia Technology, Inc., under the direction of James M. Budinger of **Lewis Research Center**. *For further information,* ***write in 51*** *on the TSP Request Card. LEW-15527*

Suppression of Range Sidelobes in Spaceborne Rain-Mapping Radar

Sidelobes are suppressed by at least 55 dB in the aircraft radar demonstration.

NASA's Jet Propulsion Laboratory, Pasadena, California

Adequate suppression of range sidelobes in a chirp pulse-compression radar system for spaceborne rain-mapping application has been demonstrated in operation of an aircraft version of the system. The radar system, which operates at a center frequency of 13.8 GHz, has been developed for operation aboard the NASA DC-8 aircraft to measure vertical rainfall-rate profiles and rain-cell dimensions.

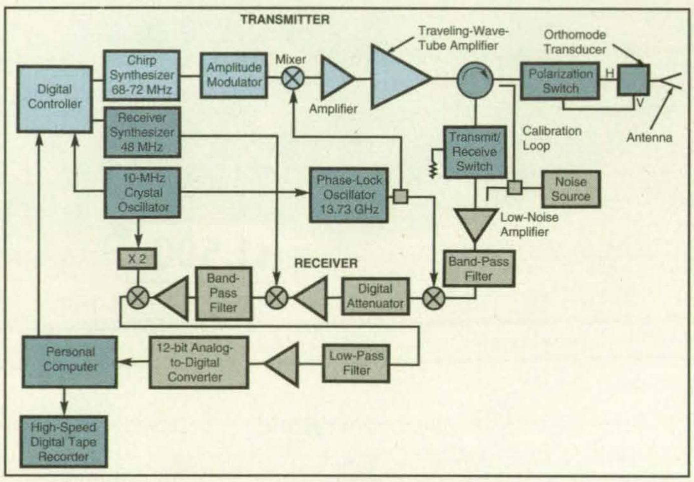


Figure 1. An **Airborne Rain-Mapping Radar** is based on pulse compression and uses 13.8-GHz carrier frequency.

Pulse-compression radar is desirable for spaceborne rain-mapping applications because it provides adequate range resolution and signal-to-noise ratio while using a relatively low peak transmitted power. To use these attributes of pulse compression to full advantages, it is necessary to suppress the pulse-compression sidelobes to a very low level. For the specific radar system, the sidelobes at middle to far range from the mainlobe response must be at least 55 dB below the peak of the mainlobe to enable the retrieval of rain signal from the surface clutter. A pulse-compression scheme must include a dedicated sidelobe-suppression feature to meet this requirement.

In the pulse-compression scheme used here, the chirp pulse signal prior to transmissions is frequency-modulated in a linear fashion with time, and is amplitude-weighted by a cosine-tapered, flat-topped waveform. The chirp signal is generated by a programmable digital frequency synthesizer. The return signal is cross-correlated with the transmitted signal.

Figure 1 shows the block diagram of the radar hardware. The transmitter produces programmable chirp waveforms of arbitrary pulse lengths and with a 4-MHz bandwidth centered about the 13.8-GHz carrier frequency. The chirp amplitude and frequency information are stored in lookup-table form in a 32 × 1,024-bit random-access memory. During transmission, the information is sent to the frequency synthesizer and the digitally-controlled attenuator at a rate of 6.7 MHz. The synthesizer generates a rectangular intermediate-frequency (IF) chirp at 70 MHz. The IF chirp is then tapered to the desired pulse shape by the attenuator. The resulting chirp signal is upconverted to radio frequency by mixing with a 13.73-GHz signal from an oscillator. This signal is coupled into a waveguide, where it is again filtered and amplified with a solid-state amplifier to a level of +13 dBm. The signal is amplified further by a traveling-wave-tube amplifier (TWTA) to a peak power level of 250 W (+54 dBm).

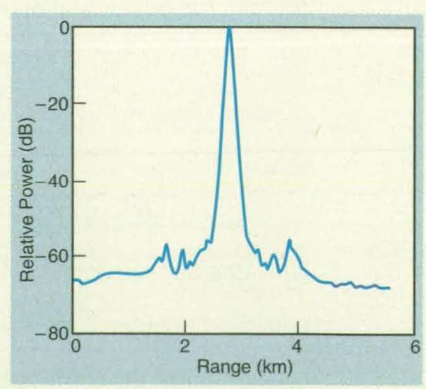


Figure 2. The **Mid-to-Far-Range Sidelobes** are suppressed to below −55 dB, as required to enable the retrieval of rain signal.

The TWTA is operated in the nonsaturated mode to maintain the desired pulse-shape characteristics. The output signal of the TWTA is directed to the antenna for transmission.

The radar echo collected by the antenna is amplified by a low-noise amplifier in the receiver. After amplification and filtering, the received signal is down-converted to an IF of 70 MHz, where it is again filtered and amplified to the proper level. The final stage of the receiver down-converts the signal to baseband, amplifies it, and digitizes it with a fast, 12-bit analog-to-digital (A/D) converter. The digital output is stored on a high-speed digital tape recorder for processing. Pulse compression is performed by the ground data processor, which cross-correlates the recorded data with a replica of the transmitted signal.

Both the laboratory and ground-based field tests conducted with this system in 1991 and 1992 have confirmed the required range sidelobe suppression performance. To verify further the performance in realistic setting, dedicated pulse compression tests were conducted in a number of science experiments during 1992 and early 1993. In these flight tests, the radar aboard the NASA DC-8 aircraft collected the clear ocean (no rain) backscatter measurements at nadir. During ground processing, several thousand of these backscatter chirps were compressed and averaged together to minimize the random noise variations. Figure 2 shows a typical result from these flight tests. Each individual chirp has a pulse duration of 40 μs and a bandwidth of 4 MHz, and the cosine taper is applied during the first ⅓ and last ⅓ of the pulse duration. The mid-to-far sidelobes are clearly suppressed below −55 dB, as required.

The same range sidelobe suppression technique can be applied to other frequencies, and therefore, could also be useful in other radar systems in which low sidelobes at mid to far range are needed.

This work was done by Eastwood Im, William J. Wilson, Fuk K. Li, Alan B. Tanner, Stephen L. Durden, and Richard F. Denning of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 87*** *on the TSP Request Card. NPO-18515*

A Motion-Compensating Image-Compression Scheme

Chrominance is used (in addition to luminance) in estimating motion.

Lyndon B. Johnson Space Center, Houston, Texas

A variable-rate digital coding scheme for the compression of color-video-image data is designed to deliver pictures of good quality at a moderate compressed-data rate of 1 to 2 bits per pixel, or of fair quality at a rate less than 1 bit per pixel. The scheme can, in principle, be implemented by use of commercially available application-specific integrated circuits. Thus far, it has been verified by use of computer simulations.

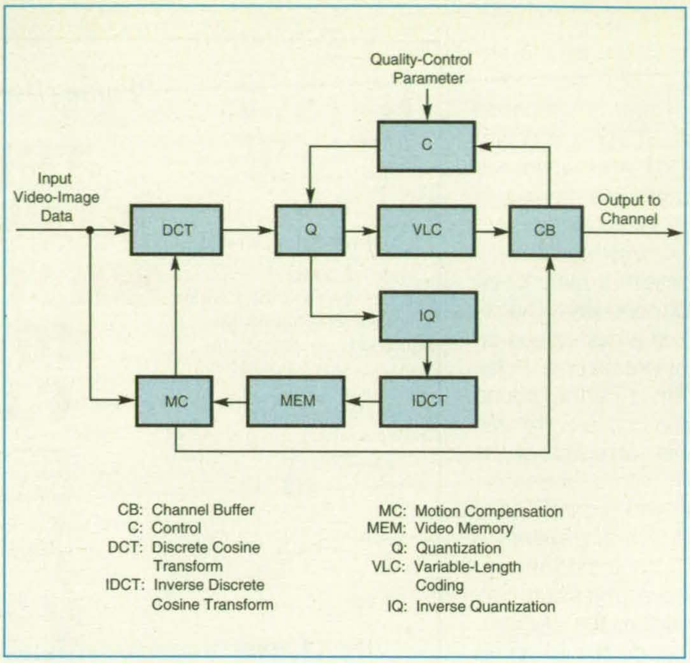
This coding scheme (see figure) incorporates elements of some prior coding schemes, including motion compensation (MC) and the discrete cosine transform (DCT). Each image frame is divided into blocks of 8×8 pixels, and each block is compared with the corresponding block in the previous frame. Blocks that exhibit little difference from the previous frame are considered stationary. The frame-to-frame displacement vector is estimated for each nonstationary (or moving) block. In this scheme, the displacement vector of each block is estimated from the luminance signal and from the two components of the chrominance signal instead of from the luminance signal alone as in older schemes: this can be an advantage in that the additional chrominance-derived information can contribute to increased accuracy of the displacement vector where luminance is low and/or detailed color information is available.

If the displacement vector of a moving block can be estimated accurately, according to a prescribed numerical error criterion, then for purposes of encoding it is assumed that that block can be reconstructed by displacement of the corresponding block in the previous frame. For such blocks, it is necessary to transmit only the displacement vectors (and not the pixel values themselves) to convey the information needed to reconstruct the present frame.

Where the displacement vectors cannot be estimated accurately, the complete blocks must be coded and transmitted. Each of these blocks is first converted into transform coefficients via a DCT process. The transform coefficients are sent to an entropy (Huffman) coder to reduce the total number of bits to be transmitted.

The MC-DCT system is capable of coding the video image at various picture-quality levels. The quantizer applied to the transform coefficients is adjusted according to the quality-control parameter that corresponds to the selected quality level. A lower bit rate can be achieved by selecting a lower picture-quality level.

This work was done by Carol Wong of Lockheed Engineering & Sciences Co. for **Johnson Space Center**. *For further information,* ***write in 89*** *on the TSP Request Card. MSC-21994*



This **MC-DCT Image-Compression Scheme** makes use of both the chrominance and the luminance information (instead of the luminance information alone) to compute the displacement vectors for motion compensation. The quality-control parameter can be adjusted to obtain a picture of higher (or lower) quality at greater (or lesser, respectively) average number of bits per pixel.

Simulating Rain Fade in a Communication System

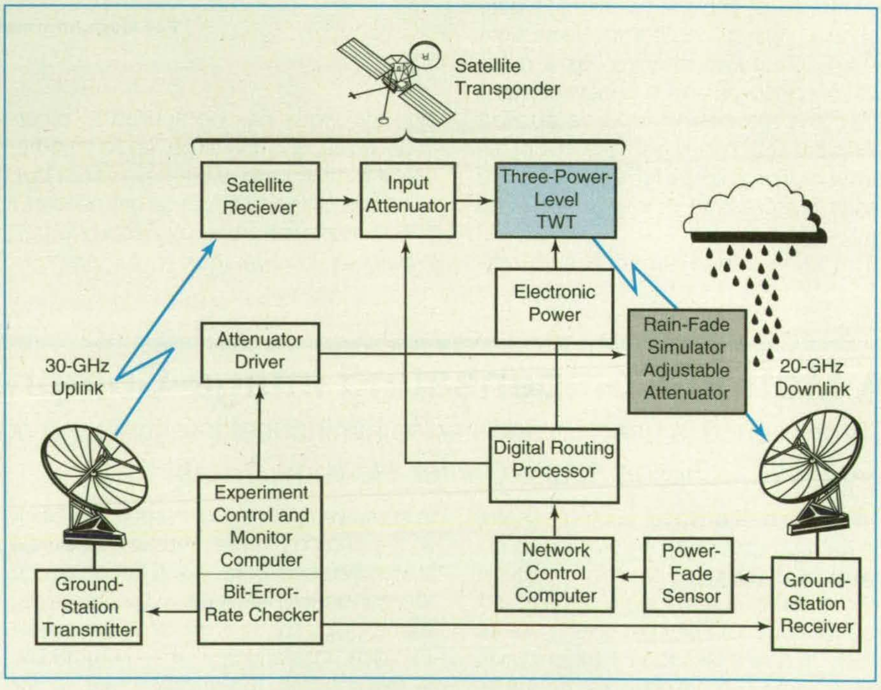
Tests will show effects of propagation through the atmosphere.

Lewis Research Center, Cleveland, Ohio

An automated, computer-controlled assembly of electronic equipment is being developed for use in simulation testing of the downlink portion of an Earth/satellite microwave digital communication system. The equipment is designed to show the effects upon the performance of the system of (1) rain-induced fading in the received signal and (2) increases in transmitted power that are meant to compensate for rain-induced fading. The design of the communication system could be improved iteratively in response to the results of the simulations, leading eventually to a design that could ensure clear, uninterrupted transmission of digital signals.

The figure illustrates the relationships among the various pieces of test equipment and the corresponding parts of the communication system. One of the two radio-frequency components that are of primary interest in this system is an adjustable attenuator that simulates rain-induced fading. Two versions of the attenuator are being developed. One of them is of the well-established rotary-vane type, in which the amount of attenuation depends on the angle between a thin vane of resistive material and the electric field in a section of waveguide. The angle and, thereby, the amount of attenuation is adjusted by a stepping-motor rotary actuator under computer control.

In the other version of the attenuator, the attenuating component is a positive/intrinsic/negative (PIN) diode, in which the amount of attenuation depends on an applied bias voltage that can be adjusted under computer control. The rotary-vane attenuator offers the advantage of precise control of attenuation, but the speed of its response is limited by the mechanical nature of some of its components. The solid-state attenuator is less precise but better able to simulate rapid onset and recession of large fades.



Automated Test Equipment under computer control simulates and measures effects of rain-induced fades on part of a communication system.

The other main radio-frequency component is a traveling-wave tube (TWT), which is the final power amplifier in the 20-GHz downlink transmitter. The TWT includes a modulation anode and is switchable among three discrete output power levels by switching among discrete anode voltage levels.

There are two computers: the network control computer (NCC) and the experiment control and monitor computer (EC&M). The NCC is responsible for the general operation of the equipment, performing operation and maintenance tasks. These tasks include automatically commanding an increase or decrease in output power to compensate for a rain fade. Thus, the NCC must indirectly control a power-control attenuator at the input to the TWT and send appropriate level-change commands to the TWT. Both of these control functions are carried out by the digital routing processor (DRP), which provides the correct timing and synchronization. EC&M contains rain-fade algorithms, files of calibration data, and stepping-motor-indexer commands and serves as the interface with the test operator. The EC&M issues the commands to change attenuation in the rain-fade simulator.

In a typical test, once the desired attenuation is reached, the signal received by the ground station would presumably fall below a threshold established previously on the basis of an acceptable bit-error-rate performance below which effective communication is lost. In response to the lower received power level, the NCC would initiate the command sequence to move the TWT from the low- to the medium-power level. As part of this process, the digital routing processor would also instruct the power-control attenuator in the transmitter to change to maintain smooth transitions between power levels and avoid pushing the TWT into gain compression.

This work was done by Kurt A. Shalkhauser and Lawrence A. Nagy of **Lewis Research Center** *and James K. Svoboda of Sverdrup Technology, Inc. Further information may be found in NASA TM-103134 [N90-28768], "Rain-Fade Simulation and Power Augmentation for Satellite Communication Systems."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. LEW-15390

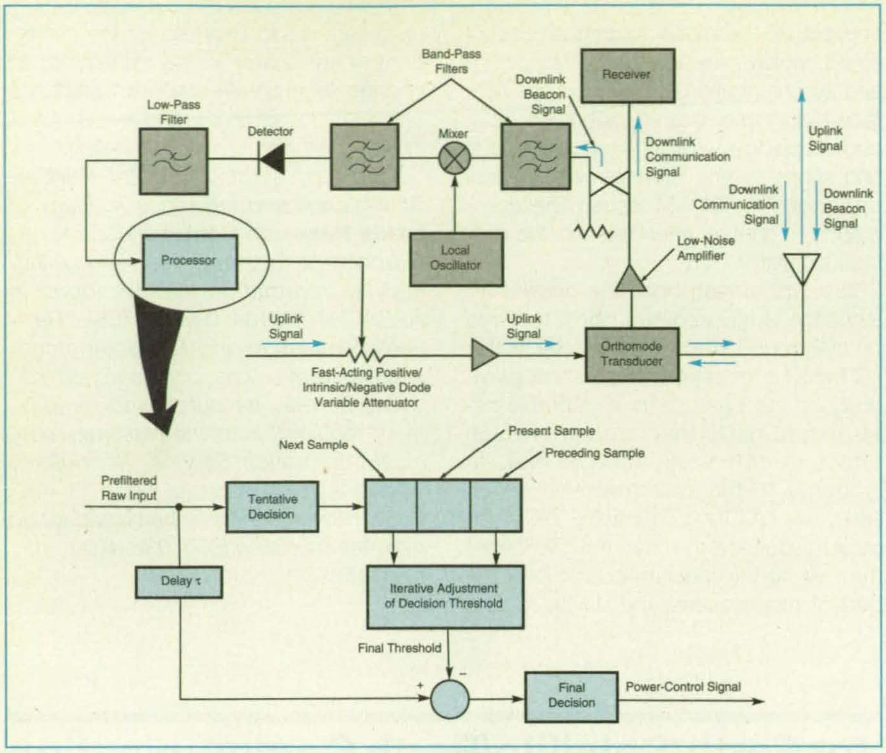
Uplink Power Control for Earth/Satellite/Earth Communication

Power would be adjusted to compensate for anticipated changes in atmospheric attenuation.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure illustrates a proposed control subsystem that would adjust the power radiated by the uplink transmitter in an Earth station/satellite relay station/ Earth station communication system. The adjustments would be made to compensate for anticipated changes in attenuation by rain ("rain fade" for short).

The raw input to the power-control



The **Control Subsystem Adjusts the Uplink Power** in response to rain fade estimated from the received downlink beacon signal.

subsystem would be a received downlink beacon signal, the amplitude of which would be affected not only by rain fade but also by scintillation, attenuation in atmospheric gases, and diurnal effects. Operating at sampling intervals of τ/m (where τ is the delay with which the subsystem would respond to input and m is a large but finite number chosen empirically), the subsystem would respond by generating a sequence of power-control signals. The subsystem would implement a maximum-likelihood-sequence-estimation technique. This technique, called "adaptive threshold detection with estimate sequence" (ATDES), is based partly on the assumption that the rain fade at intervals of τ/m is a conditionally stationary random process in which each sample is influenced only by the immediately preceding sample. (That is, rain-fade samples would be characterized by a first-order Markov process.)

The raw input signals would first be preamplified, prefiltered, and sampled at intervals of τ/m. Rolling sequences of three consecutive samples would be processed and compared with decision thresholds to generate a sequence of decisions concerning adjustments of the transmitter power. Initial, tentative decision thresholds would be set according to externally generated data on scintillation, atmospheric attenuation, and diurnal effect. Then the decision thresholds would be adjusted iteratively at intervals of τ/m according to the results of comparisons between the thresholds and the samples, to yield final decision thresholds after processing time τ. Samples that were delayed but otherwise unprocessed would be compared with the final decision thresholds to generate the sequence of control decisions.

This work was done by Dayamoy Chakraborty of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 105*** *on the TSP Request Card. NPO-18854*

Verifying Stiffness Parameters of Filament-Wound Cylinders

Experimental data are analyzed by use of straightforward equations.

Marshall Space Flight Center, Alabama

Predicted engineering stiffness parameters of filament-wound composite-material cylinders can be verified with respect to experimental data, by use of equations developed straightforwardly from the applicable formulation of Hooke's law. The equations were derived in an engineering study of filament-wound rocket-motor cases but are also applicable to other cylindrical pressure vessels made of orthotropic materials.

The figure illustrates the essential geometric features that are involved in the analysis. The interior of the cylindrical vessel is pressurized, and the resulting axial and radial strains are computed from measurements taken by extensometers and/or strain gauges placed far from the ends. This placement assures that the shear stresses and strains are negligible at the gauged locations.

Under these conditions, the only stresses at the gauged locations are the axial stress,

$$\sigma_1 = \frac{PD}{4t}$$

(where P = the pressure, D = the mean diameter, and t = thickness of the wall), and the hoop stress,

$$\sigma_2 = 2\sigma_1 = \frac{PD}{2t}$$

The applicable Hooke's-law equations lead to

$$C_1 = \frac{\varepsilon_1}{\sigma_1} = \frac{4t\varepsilon_1}{D} = S_{11} + 2S_{12}, \text{ and}$$

$$C_2 = \frac{\varepsilon_2}{\sigma_1} = \frac{4t\varepsilon_2}{DP} = S_{12} + 2S_{22}$$

where ε_1, and ε_2, are the axial and hoop strains, respectively. S_{11}, S_{12}, and S_{22} denote the stiffness parameters that are sought. These parameters are related to Young's moduli E_{11} and E_{22} and to Poisson's ratio υ_{12} via

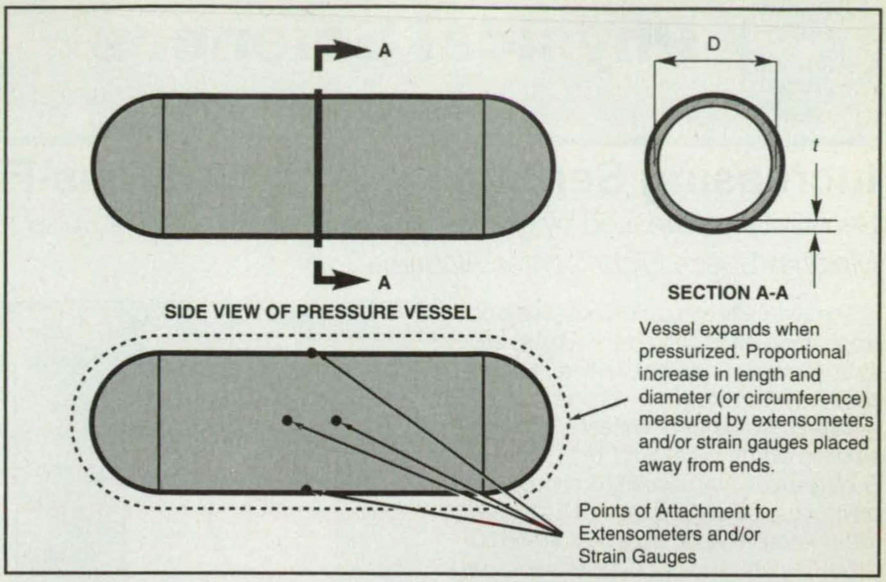
$$S_{11} = \frac{1}{E_{11}};\ S_{22} = \frac{1}{E_{22}};\ S_{12} = -\frac{\upsilon_{12}}{E_{11}}$$

C_1 and C_2 are computed from the measurements.

Thus far, there are two equations that relate the measurement data and the three unknowns S_{11}, S_{12}, and S_{22}. A third equation can be formulated by applying the method of least squares to the differences between the S_{ij} and the corresponding predicted engineering stiffness parameters A_{ij} (where ij = 11, 22, or 12). The result is

$$S_{22} = \frac{2}{21}\left(5C_2 - 2C_1\right) + \frac{1}{21}\left(4A_{11} + A_{22} - 2A_{12}\right)$$

The three equations can then be solved together to obtain the three unknowns. Thus, in effect, the experimental data are used to verify and to enhance the accuracy of the predicted stiffness parameters A_{ij}.



Measurements of a Few Principal Dimensions are used to analyze the stiffness parameters according to the method described in the text.

This work was done by V. Vereraime and M. Rheinfurth of **Marshall Space Flight Center**. *Further information may be found in NASA TP-2117 [N83-16400], "Identification and Management of Filament-Wound Case Stiffness Parameters."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700. MFS-28626

Increasing Sensitivity in Continuous-Flow Electrophoresis

Sensitivity is increased by gradients in the concentration of buffer and thickness of the chamber.

Marshall Space Flight Center, Alabama

The sensitivity of a continuous-flow electrophoresis (CFE) chamber — i.e., its ability to separate particles of different mobilities — can be increased by introducing lateral gradients in the concentration of buffer solution and thickness of the chamber. Such gradients, with resulting enhanced separation, can be achieved in a CFE chamber with a wedge-shaped cross section and collateral flow. This improved CFE chamber can enable improved separations of the homogeneous components of mixtures of a variety of biologically important substances.

The left part of Figure 1 schematically illustrates the trajectories followed by two populations, A and B, of charged particles in a conventional CFE chamber; *Y* is the direction in which the buffer is flowing (typically at a constant rate), and *X* is the direction in which the particles move in response to the applied electric field. In a conventional CFE chamber, the trajectories of populations A and B are straight lines because there is no lateral gradient (gradient along *X*). The right part of Figure 1 schematically illustrates the trajectories followed by the same two populations in a similar chamber in which there is a lateral gradient that increases the lateral velocity and decreases the vertical velocity with increasing *X*. The trajectories are curved, diverging more with increasing *Y* than they do in the conventional CFE chamber. Consequently, fractions A and B collected at the end (bottom in this figure) of the chamber are separated more widely than they are in conventional CFE.

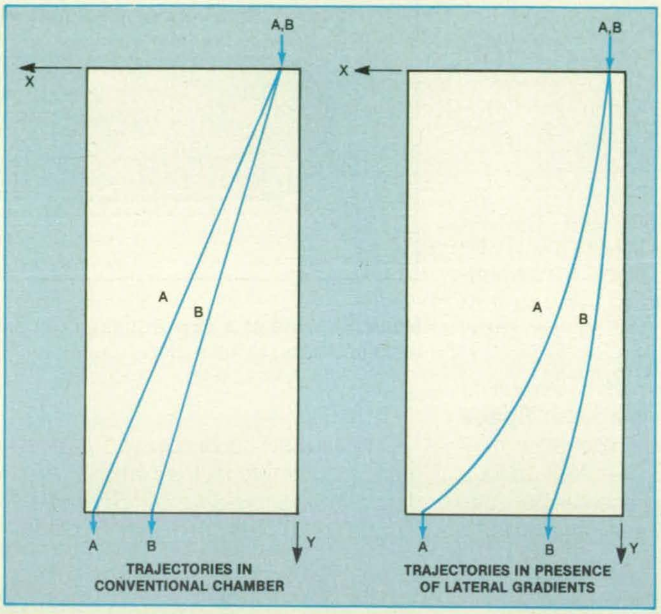


Figure 1. The **Trajectories Followed by Populations A and B** in conventional CFE are straight, while they are curved in the presence of lateral gradients in velocity. The curvature enhances the separation attained at the outlet end (lower end in this figure) of the chamber.

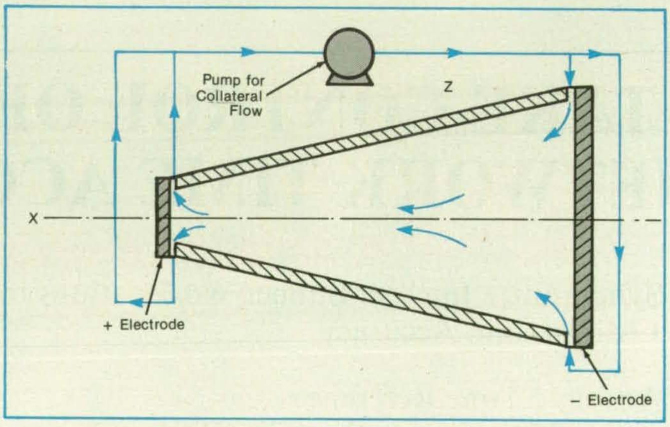


Figure 2. **Modifications of the CFE Chamber** to produce the desired gradients include a wedge-shaped (instead of rectangular) cross section and the imposition of a collateral flow.

The key feature of the improved CFE chamber is a wedge-shaped cross section (instead of one that is rectangular). The wedge cross section gives rise to the desired lateral (along *X*) gradient in the axial (along *Y*) velocity of the fluid because the velocity of a fluid flowing between two plates varies with the square of the width of the gap between them. The wedge cross section also gives rise to a lateral gradient in the strength of the applied lateral electric field because the electrical conductivity varies with the cross-sectional area available for the passage of current, and hence changes along *X*, the direction of electrophoresis. Finally, because the velocity of a fluid in a conduit varies inversely with the cross-sectional area, the electro-osmotic velocity varies with *X*; this effect can be enhanced by manipulating the ζ potential of the walls.

The top part of Figure 2 schematically illustrates a CFE chamber in which a wedge-shaped cross section was simulated as a series of step changes in chamber thickness. When used to separate rabbit fixed red blood cells from calf fixed red blood cells, this chamber yielded a greater than 90-percent increase in sensitivity over that of a conventional chamber of rectangular cross section. The effect of the lateral gradient in electro-osmotic flow can be enhanced by superimposing a uniform collateral flow (across the chamber) along the direction of electrophoresis, as shown in the lower part of Figure 2.

Two designs for producing a lateral gradient in the concentration of buffer solution have been proposed: In one, a low-concentration solution would enter through a main inlet, and a high-concentration solution would be mixed in via a tube that would extend across the chamber at its upstream end and that would be perforated with openings, the spatial frequency of which would vary with lateral position (*X*). In the other proposed design, mixing would be done outside the chamber, and a series of solution-feed tubes in which the concentrations change with their positions across the upstream end would substitute for the main inlet of a conventional CFE chamber.

This work was done by Rizwan Sharnez

and David W. Sammons of the University of Arizona for **Marshall Space Flight Center**. *For further information,* ***write in 30*** *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

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Refer to MFS-26176, volume and number of this NASA Tech Briefs *issue, and the page number.*

Free-Flow Open-Chamber Electrophoresis

Electro-osmosis is used to minimize net deflection of the sample.

Marshall Space Flight Center, Alabama

Free-flow open-chamber electrophoresis is a variant of free-flow electrophoresis that is performed in a chamber with open ends and in which the velocity of electro-osmotic flow is adjusted to be equal to and opposite the mean electrophoretic velocity of the sample (see Figure 1). Thus, particles that have electrophoretic mobilities greater than the mean mobility of the sample particles move toward the cathode, while those with mobilities less than the mean move toward the anode. This technique can be applied to the separation of the components of mixtures of biologically important substances.

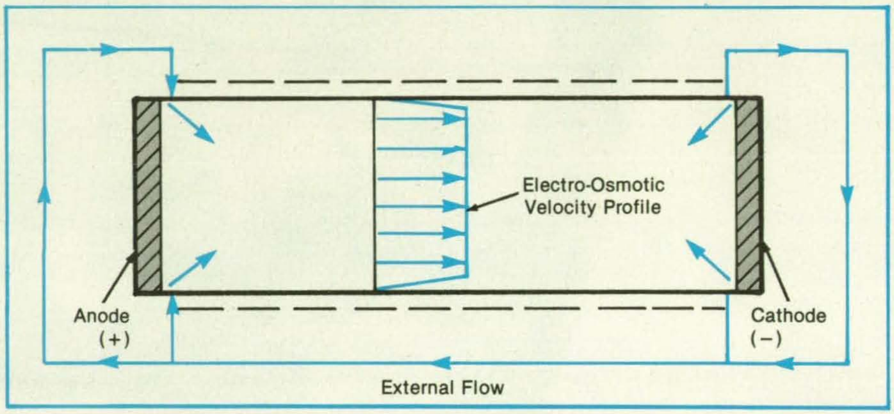

Figure 1. The **Principle of Free-Flow Open-Chamber Electrophoresis** is illustrated schematically. The ζ potential of the walls is adjusted to match the mean ζ potential of the sample. This results in a plug-shaped electro-osmotic velocity profile with magnitude equal and direction opposite those of the mean electrophoretic velocity of the sample.

As with other modes of free-flow electrophoresis, the sensitivity can be enhanced by use of a tapered chamber. A configuration that enhances sensitivity appears in the upper part of Figure 2; the sample is injected at the point of widest gap.

An alternative strategy for obtaining electro-osmosis with the desired plug-shaped velocity profile is illustrated in the lower part of figure 2. Two flat plates, AA′ and BB′, are placed in a free-flow electrophoresis chamber close to opposite walls of the chamber. The surfaces that bound the narrower gaps are made neutral, whereas the surfaces that bound the wider gaps are negatively charged; their ζ potential is adjusted to obtain the desired electro-osmotic velocity. Thus, fluid pumped toward the cathode by electro-osmosis (in the wider gap) returns to the anode via the narrower gaps.

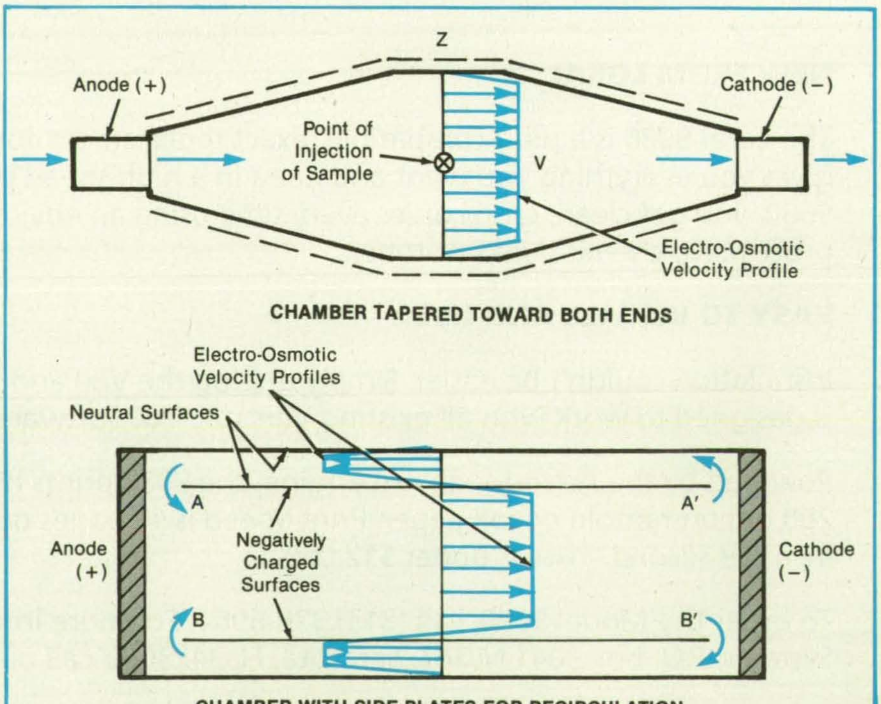

Figure 2. Two **Alternative Designs** for free-flow open-chamber electrophoresis are shown.

This work was done by Rizwan Sharnez and David W. Sammons of the University of Arizona for **Marshall Space Flight Center.** *For further information,* ***write in 4*** *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

Richard A. Haney
Program Director
The University of Arizona
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Annular-Cross-Section CFE Chamber

The annular shape virtually eliminates electro-osmosis and transverse velocity gradients.

Marshall Space Flight Center, Alabama

A proposed continuous-flow-electrophoresis (CFE) chamber of annular cross section would offer advantages over a conventional CFE chamber, and even over the wedge-cross-section chamber described in "Increasing Sensitivity in Continuous-Flow Electrophoresis" (MFS-26176). In comparison with wedge-shaped chamber, a chamber of annular cross section virtually eliminates such wall effects as electro-osmosis and transverse gradients of velocity.

In a wedge-cross-section chamber, the sensitivity increases with the angle θ, between the two plates. In the upper limit of θ (360°), the wedge cross section would be transformed into an annulus (see figure); thus, the principle by which sensitivity can be enhanced through an annular design is no different from that of a wedge. Moreover, because velocity gradients perpendicular to the electric field in the wedge would be replaced by velocity gradients parallel to the field (in the radial direction) in the annulus, particles that have the same mobility would be subjected to virtually identical conditions of electric-field strength, temperature, velocity, and the like. In principle, this should lead to a higher chamber efficiency (lesser artifactual dispersion).

The larger cross-sectional area of an annulus should make it possible to use a much higher throughput. However, only the radially inner part (about half) of the annulus would provide a favorable gradient in v_y; i.e., a velocity that decreases along the direction of electrophoresis (radially inward). Consequently, if the gradient in v_y is to be exploited, separation would have to be restricted to the inner part of the chamber ($r \geq R_c$ in the figure).

As in the wedge-cross-section chamber, the sensitivity of the annular chamber can be enhanced by incorporating a gradient maker and radial (collateral) flow. Setting up a radial velocity gradient that would match the final (downstream) distribution of velocity in the annulus would reduce the length of the entrance zone substantially, a feature that could be vital in the design of an annular-cross-section CFE chamber with a gap wider than 0.5 cm. One disadvantage of the annular-cross-section chamber in comparison with the wedge-cross-section chamber is that it would have less surface area per unit volume, and would therefore be less stable with respect to heat loss by thermal convection.

This work was done by Rizwan Sharnez and David W. Sammons of the University of Arizona for **Marshall Space Flight Center.** *For further information,* ***write in 59*** *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

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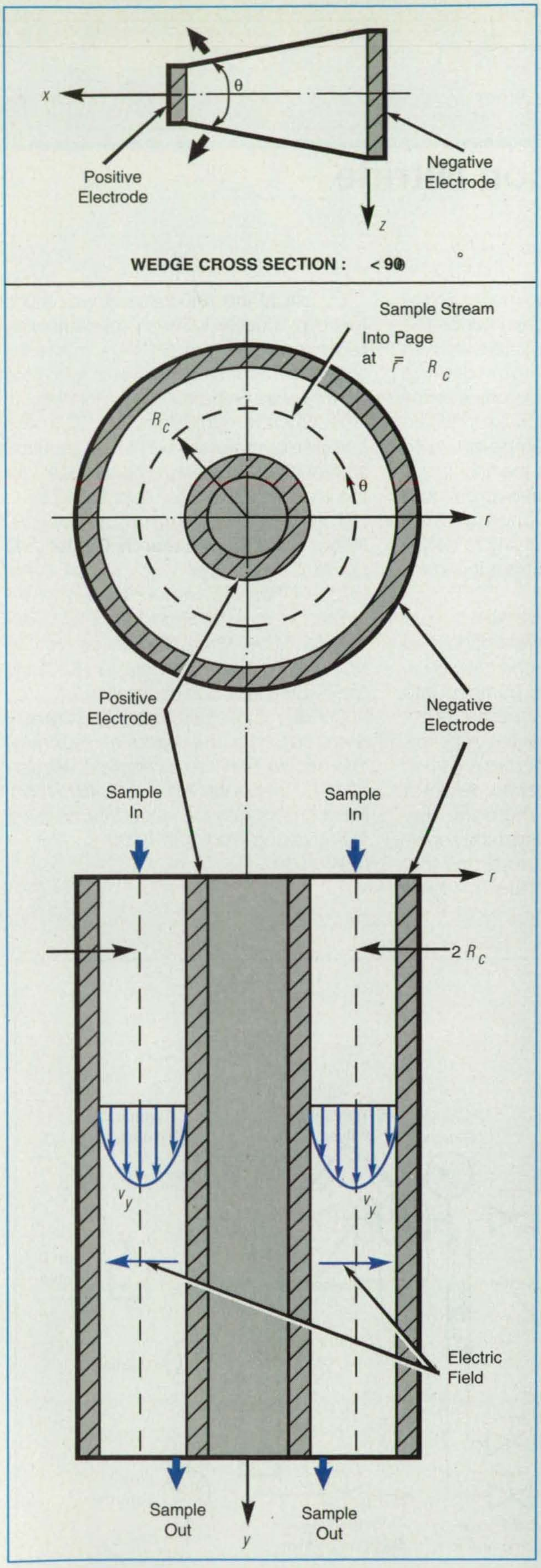
Tucson, AZ 85719

Refer to MFS-26178, volume and number of this NASA Tech Briefs issue, and the page number.



The **Annular-Cross-Section CFE Chamber** could be regarded as evolving via an increase in the θ of a wedge-cross-section chamber to 360°.

Synthesis of a Precursor of Silicon Nitride

$Si(NH)_2$ is prepared by reaction of NH_3 with $Si(SCN)_4$.

Lewis Research Center, Cleveland, Ohio

One promising route toward the production of highly pure, finely divided, easily sinterable silicon nitride (Si_3N_4) involves the thermal decomposition of silicon diimide [$Si(NH)_2$] prepared by the ammonolysis of $Si(SCN)_4$ in CH_3CN and purified by the complete extraction of byproduct NH_4SCN by the use of ammonia at a temperature and pressure above its critical point. In an older method in which $Si(NH)_2$ is prepared by the ammonolysis of $SiCl_4$, it has proven difficult to remove all of the byproduct NH_4Cl from the $Si(HN)_2$.

In the older method, highly pure Si_3N_4 is synthesized via the preparation of the $Si(NH)_2$, which is then thermally decomposed to silicon nitride according to the reaction

$$3Si(NH)_2 \rightarrow Si_3N_4 + 2NH_3$$

The precursor silicon diimide is made by the reaction of silicon tetrachloride with dry ammonia:

$$SiCl_4 + 6NH_3 \rightarrow Si(NH)_2 + 4NH_4Cl$$

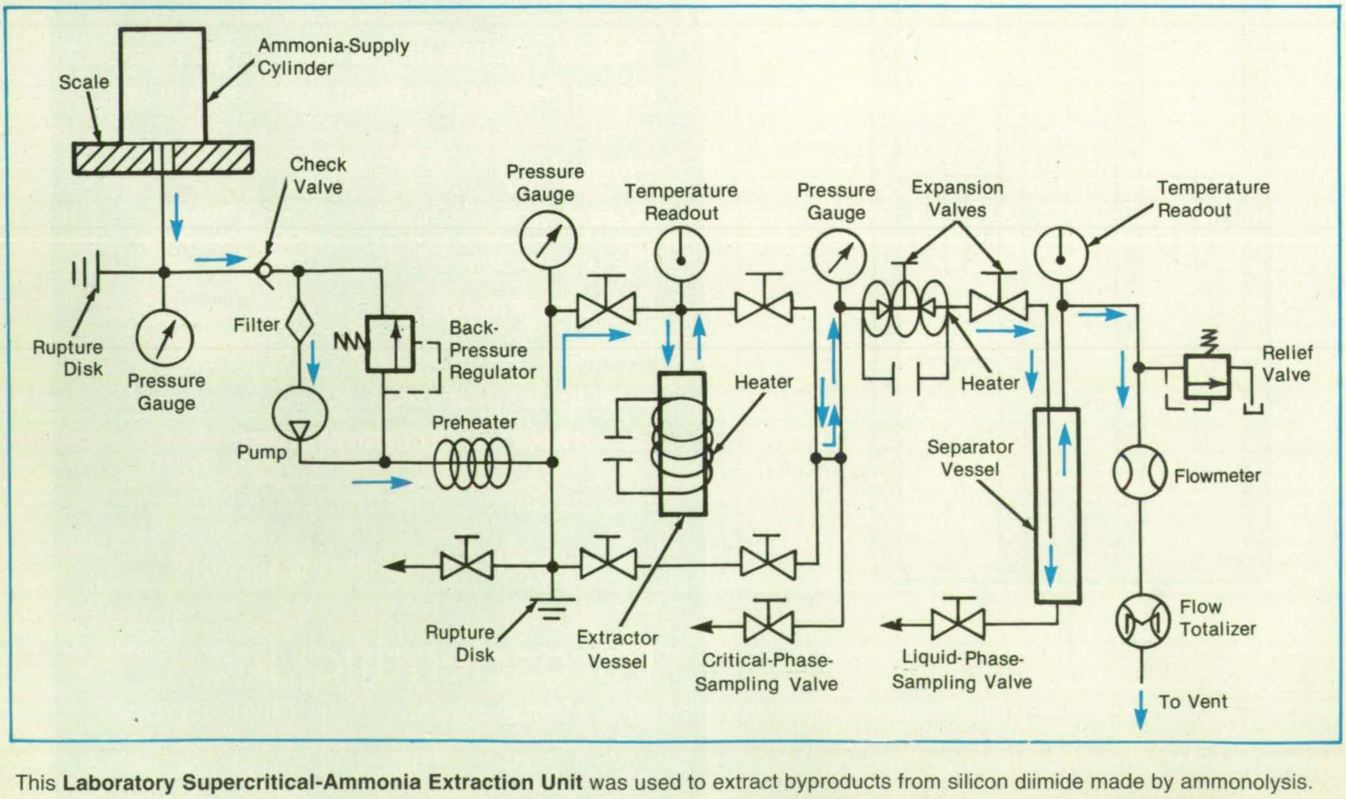
Most of the byproduct ammonium chloride is extracted with liquid ammonia. The remaining chloride impurity interferes with the pyrolysis of the silicon diimide because the chloride undergoes a series of chemical reactions that make it necessary to use a higher temperature to remove the chlorine from the final product, silicon nitride. The new procedure for the synthesis of silicon diimide emerged in the context of trying to devise a more efficient way to extract the chloride byproduct.

The experiments in extraction by use of supercritical ammonia were performed in the apparatus shown schematically in the figure. Ammonia was pumped into and through an extractor vessel. After emerging from this vessel, the supercritical solution was flashed across a heated expansion valve into a separator vessel at atmospheric pressure, where the dissolved solutes precipitated and the supercritical solvent expanded to a gas that was vented through a flowmeter to a fume hood.

By use of this apparatus, it was found that byproduct NH_4Cl was not completely removed from the $Si(NH)_2$ made by ammonolysis of $SiCl_4$. However, when the $Si(NH)_2$ was prepared by ammonolysis of $Si(SCN)_4$, the byproduct NH_4SCN was completely removed by the supercritical ammonia, thereby providing the basis for the improved synthetic route to Si_3N_4.

This work was done by Warren H. Philipp of **Lewis Research Center** *and Linda Cornell and Y. C. Lin of Case Western Reserve University. Further information may be found in NASA TM-102570 [N90-21843], "Studies on the Use of Supercritical Ammonia for Ceramic Nitride Synthesis and Fabrication."*

Copies may be purchased [prepayment required] from the National Technical Information Service, Springfield, Virginia 22161, Telephone No. (703) 487-4650. Rush orders may be placed for an extra fee by calling (800) 336-4700.
LEW-15397



This **Laboratory Supercritical-Ammonia Extraction Unit** was used to extract byproducts from silicon diimide made by ammonolysis.

Polybenzimidazoles Via Aromatic Nucleophilic Displacement

These polymers exhibit good thermal, thermo-oxidative, and chemical stability, and high mechanical properties.

Langley Research Center, Hampton, Virginia

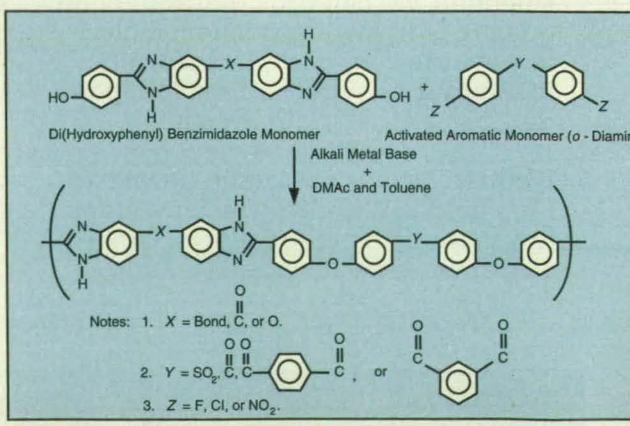
Soluble polybenzimidazoles (PBI's) have been synthesized by the nucleophilic displacement reaction of di(hydroxyphenyl)-benzimidazole monomers with activated aromatic difluoride compounds in the presence of anhydrous potassium carbonate. Heretofore, commercial PBI's were made by condensation reactions of aromatic bis(*o*-diamines) with aromatic diacid derivatives. The new synthesis, using benzimidazole monomers, is more economical, and the new PBI's can be processed more easily than can commercial PBI, without loss of desirable physical properties.

The glass-transition temperatures (Tg's) of the new PBI's lie in the range from 264 °C to 352 °C — much lower than those of their older commercial counterparts, which exhibit Tg's of about 400 °C. Because of the lower Tg's, these polymers are more easily compression molded than the commercial PBI's. These newer PBI's are soluble in cold N,N-dimethylacetamide (DMAc), whereas it is necessary to apply heat and pressure to dissolve the commercial PBI's in DMAc. The ease of solubility of the newer PBIs facilitates the formation of thin films — and carbon fiber prepeg.

The figure illustrates a typical synthesis. In the experiments, the leaving groups were F; in principle, they could also be Cl or NO_2. The base used in the experiments was pulverized anhydrous potassium carbonate; in principle, it could also be sodium carbonate, potassium hydroxide, or sodium hydroxide. The solvent used in the experiments was a mixture of DMAc and toluene; other solvents such as N-methylpyrrolidinone, diphenylsulfone, or sulfolane can be used. A wide variety of other monomers, in which *X* and *Y* are other groups and/or in which the OH subgroups of the hydroxyphenyl groups are *meta* catenated, could also be used.

This work was done by John W. Connell and Paul M. Hergenrother of **Langley Research Center** *and Joseph G. Smith of the University of Akron. For further information,* ***write in 95*** *on the TSP Request Card.*

This invention is owned by NASA, and a patent application has been filed. Inquires concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 20].
Refer to LAR-14643.



Aromatic Nucleophilic Displacement can be used to synthesize polybenzimidazoles

Computer Programs

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Mechanics

Boundary-Layer Code for Supersonic Combustion

HUD predicts the development of boundary layers on two-dimensional or axisymmetric bodies.

HUD is an integral computer code based on the Spaulding–Chi method for predicting the development of boundary layers in laminar, transitional, and turbulent regions of flows on two-dimensional or axisymmetric bodies. This program was developed by use of integral-momentum, moment-of-momentum, and energy equations. It can approximate nonequilibrium velocity profiles as well as local surface friction in the presence of a pressure gradient. It can predict the transfer of heat in a turbulent boundary layer in the presence of a high axial presure gradient. It provides for pressure gradients both normal and lateral to surfaces.

Because the program is designed with particular emphasis on its applicability to supersonic combustion, real-gas-flow effects are included. As a result, HUD can be used to estimate requirements for cooling scramjet engines. Because of this capability, the HUD program has been incorporated into several scramjet-cycle-performance-analysis codes, including SCRAM (ARC-12338) and SRGULL (LEW-15093).

The HUD program is written in FORTRAN 77 and is meant to be machine-independent. On an IBM PC-compatible computer under PC-DOS, HUD requires 156K of memory. HUD was developed in 1970.

IBM PC and PC-DOS are registered trademarks of International Business Machines, Inc.

This program was written by S. Z. Pinckney of Langley Research Center and J. T. Walton of **Lewis Research Center**. *For further information* ***write in 25*** *on the TSP Request Card.*
LEW-15163

Computing Incompressible Flows With Free Surfaces

Surface tension at free surfaces is replaced by a volume force derived from a continuum-surface-force model.

RIPPLE is a computer program for modeling transient, two-dimensional flows of incompressible fluids with surface tension on free surfaces of general shape. Free-surface flows of incompressible fluids are integral parts of natural and industrial processes. The behavior of a fluid can be especially difficult to understand and quantify when the free surfaces have appreciable surface tension and arbitrarily complicated shapes.

Examples of such flows can be found in nuclear-reactor thermal hydraulics, internal-combustion-engine fuel sprayers, ink-jet printers, the application of industrial surfactants, formation of raindrops, casting and mold filling processes, dynamics of drops and bubbles, and cryogenic liquids in microgravity. Mathematical modeling of such flows poses a significant challenge because a required boundary condition must be applied to a transient, irregular surface (the free surface) that is ideally a discontinuity. Surface tension frequently constrains the accuracy with which the resulting boundary conditions are applied in numerical models.

A two-step projection method is used to solve for incompressible flow, with the pressure Poisson equation solved via a robust incomplete Cholesky conjugate-gradient technique. Momentum advection is estimated with a technique very similar to the weakly monotonic upwind method of van Leer. Flow obstacles and curved boundaries interior to the computational mesh are representable with a partial-cell treatment that borrows from two-phase flow physics.

The numerical scheme of RIPPLE is based on a finite-difference solution of a set of coupled partial differential equations that govern the flow of an incompressible fluid. Finite-difference solutions to the Navier–Stokes equations of incompressible flow are obtained on an Eulerian, rectilinear mesh in Cartesian or cylindrical geometry. Free surfaces are represented with volume-of-fluid data on the mesh. Surface tension is modeled as a volume force derived from the continuum-surface-force model, which gives RIPPLE both robustness and accuracy in modeling surface-tension effects at the free surface. RIPPLE can also model wall adhesion effects.

Documentation for RIPPLE reviews the governing equations, discusses finite-difference conventions, and presents finite-difference expressions used by the software to approximate the governing equations. Three example RIPPLE calculations are presented: (1) breakup of a capillary jet, (2) reorientation of a propellant, and (3) tank flows induced by an internal jet. These examples display the ability of RIPPLE to compute a wide variety of incompressible flows with free surfaces. The documentation also includes a detailed user's manual that should enable a new user to compute easily with RIPPLE.

RIPPLE is written in FORTRAN 77 for use with computers running UNIX. RIPPLE has been successfully compiled and executed on a Sun SPARC workstation running SunOS 4.1.1. It can be easily ported, compiled, and run on virtually any machine with a FORTRAN 77 compiler. As of October 1993, RIPPLE has been ported and run on other UNIX computing platforms such as DEC, VAX, APOLLO, SGI, IBM, HP, and CRAY. It has also been easily ported to personal computers using, for example, the NDP/386 FORTRAN compiler by Phar Lap with DOS extender. A new X-Windows graphics capability is available from the author upon request. The standard distribution medium for this program is a 0.25-in. (6.35-mm) streaming-magnetic-tape cartridge in UNIX tar format. RIPPLE was developed in 1991. Two other distribution media are available: (1) 3.5-in. (8.9-cm) floppy disk in either UNIX, DOS, or Macintosh format, or (2) anonymous ftp directly from the author's Sun workstation.

SunOS and SPARC are registered trademarks of Sun Microsystems, Inc.

This program was written by D. Kothe of Los Alamos National Laboratory for **Lewis Research Center**. *The author can be reached at (505) 667-9089 or via e-mail at dbk@mizzou.lanl.gov. For further information,* ***write in 9*** *on the TSP Request Card. LEW-15352*

Estimating Lives of Space Shuttle Parts

Optimizations can be performed on a probabilistic basis.

Fracture-mechanics analyses that are based partly on the assumption of worst-case conditions in defining life-controlling parameters often result in underestimates of the lives of critical structural components of the Space Shuttle main engine. In reality, the probability of occurrence for any individual worst-case condition is low, and the probability of a combination of worst-case conditions is infinitesimal. Thus, components designed according to such an analysis tend to be used inefficiently and/or to have excessive weight, with consequent reduction in payload capacity and increase in the cost of operations. The SSPOC (Space Shuttle Probabilistic Optimization Code) computer program, which implements a probabilistic mathematical model, accepts defined distributions of the parameters that control the life of the Space Shuttle main engine. SSPOC can be used to perform tradeoff studies to optimize between service life and an acceptable level of risk, with accuracy greater than has been available until now.

SSPOC draws upon the central idea of statistics; that the behavior of a large group can be inferred from the behavior of a small sample of its members. By sampling the normal, lognormal, Weibull, bivariate, and beta statistical distributions of life-controlling parameters, SSPOC computes rates of occurrence of significant events. Such an event occurs, for example, when a defective part mistakenly passes inspection, when a part is replaced, or when a part is rejected in a more-stringent inspection. The output of SSPOC also includes the probability of removal and failure of parts, along with the number of surviving parts for each interval of inspections. A final table provides a summary for all locations over all intervals, and it can be used to detect overall, large-scale trends or to compare different design configurations.

SSPOC is written in FORTRAN 77, and its user interface is written in PASCAL. The user interface can be implemented only on an IBM PC-compatible (AT or better) computer and requires TURBO PASCAL 5.0 or higher. SSPOC was developed by use of Microsoft FORTRAN but can be successfully implemented under other FORTRAN compilers that support Namelist input. The FORTRAN code has been successfully implemented on DEC VAX-series computers running VMS. The program is available on a 5.25-in. (13.34-cm), 360 K MS-DOS-format diskette (standard distribution medium) or in DEC VAX BACKUP format on a 9-track, 1,600-bit/in. (630-bit/cm) magnetic tape or a TK50 tape cartridge. The program source code, executable code, and data files are compressed by use of the PKWARE archiving tools. The utility software to unarchive the files, PKUNZIP.EXE, is included.

SSPOC was developed in 1989.

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This program was written by Tommie Watkins, Jr., and Chuck G. Annis of United Technologies Corp. for **Marshall Space Flight Center**. *For further information,* ***write in 65*** *on the TSP Request Card.* *MFS-28647*

Physical Sciences

Program Supplies Properties of Parahydrogen

Thermodynamic and transport properties are interpolated from data-base entries.

The National Bureau of Standards Parahydrogen Properties Database (NBS+_PH2) computer program was developed to provide selected thermal and transport properties of parahydrogen that match the 1981 parahydrogen data of the National Bureau of Standards (now called the National Institute of Standards and Technology). The program was created to be linked with propulsion-simulation programs, which require a mathematical model of parahydrogen that can cover a wide range of pressures and temperatures. NBS+_PH2 can provide data on parahydrogen for pressures from 10 kPa to 16 MPa and temperatures from 20 to 104 K.

NBS+_PH2 is set up as a single FORTRAN subroutine. When pressure and temperature or enthalpy are sent to it through the FORTRAN call statement, the thermodynamic and transport properties at the given conditions are returned to the calling program. Linear interpolation is used to calculate between database entries when necessary. NBS+_PH2 can provide the following properties of parahydrogen: density, thermal conductivity, viscosity, Prandtl number, enthalpy, specific heat, and speed of sound.

NBS+_PH2 is a data-base program written in FORTRAN 77 and is designed to be machine-independent. Although a user-interactive test program for gaining access to NBS+_PH2 is provided in the distribution package, NBS+_PH2 is intended to be linked with simulation programs. The data base and interactive test program have been used successfully on a Sun4-series computer running UNIX, an IBM PC-series compatible computer running MS-DOS (using Lahey F77L), and a DEC VAX computer running VMS. The standard distribution medium for this program is a 5.25-in. (13.34-cm), 360K MS-DOS format diskette. The contents of this diskette are compressed with the PKZIP archiving tools. The program to uncompress the files, PKUNZIP.EXE, is included on the diskette. A sample MS-DOS executable code is provided. NBS+_PH2 is also available on a 0.25-in. (6.35-mm) streaming-magnetic-tape cartridge in UNIX tar format and a 9-track, 1,600-bit/in. (630-bit/cm) magnetic tape in DEC FILES-11 format. Documentation is included in the price of the program. NB+_PH2 was developed in 1992.

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This program was written by J. T. Walton of **Lewis Research Center**. *For further information,* ***write in 20*** *on the TSP Request Card.*
LEW-15505

Computing Thermal Imbalance Forces on Satellites

HEAT.PRO computes momentum fluxes associated with thermal radiation.

The HEAT.PRO computer program calculates the imbalance force caused by heating of the surfaces of a satellite. The heated body of satellite reradiates energy at a rate that increases with its temperature, losing the energy in the form of photons. By conservation of momentum, the flux of momentum carried out of the body by the photons creates a reaction force against the radiating surface, and the net thermal force can be observed as a small perturbation that affects long-term orbital behavior of the satellite. HEAT.PRO calculates this thermal imbalance force and then determines its effects on the orbit of the satellite, especially where the shadow cast by the Earth causes periodic changes in the thermal environment around the satellite.

HEAT.PRO implements a finite-element routine called PDE2D, which incorporates properties of materials, to determine the temperatures at the surfaces of a solar panel. The nodal temperatures in the finite-element mathematical model are computed at specified time steps and are used to determine the magnitude and direction of the thermal force on the spacecraft. These calculations are based on the orientation of the solar panel and the position of the satellite with respect to the Earth and Sun. It is necessary to have accurate, current knowledge of surface emissivities, thermal conductivities, heat capacities, and densities of materials. These parameters, which can change because of degradation of materials in the outer-space environment, influence the nodal temperatures that are computed and thus the calculated thermal imbalance forces.

HEAT.PRO was written in FORTRAN 77 for Cray-series computers running UNICOS. The source code contains directives for, and is used as, input to the required partial-differential-equation-solving routine, PDE2D (available from IMSL, Inc. Houston, Texas). HEAT.PRO is available on a 9-track, 1,600-bit/in. (630-bit/cm) magnetic tape in Unix tar format (standard distribution medium) or a 0.25-in. (6.35-cm) streaming-magnetic-tape cartridge in Unix tar format. HEAT.PRO was developed in 1991.

Cray and UNICOS are registered trademarks of Cray Research, Inc. Unix is a trademark of AT&T Bell Laboratories. PDE2D is a trademark of IMSL, Inc.

This program was written by Yvonne Vigue, Robert E. Schutz, Granville Sewell, and Pothai A. M. Abusali of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information,* ***write in 63*** *on the TSP Request Card.*
NPO-18665

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Mechanics

Automatically Locking/Unlocking Orthotic Knee Joint

This joint would be safer and easier to use than conventional orthotic knee joints are.

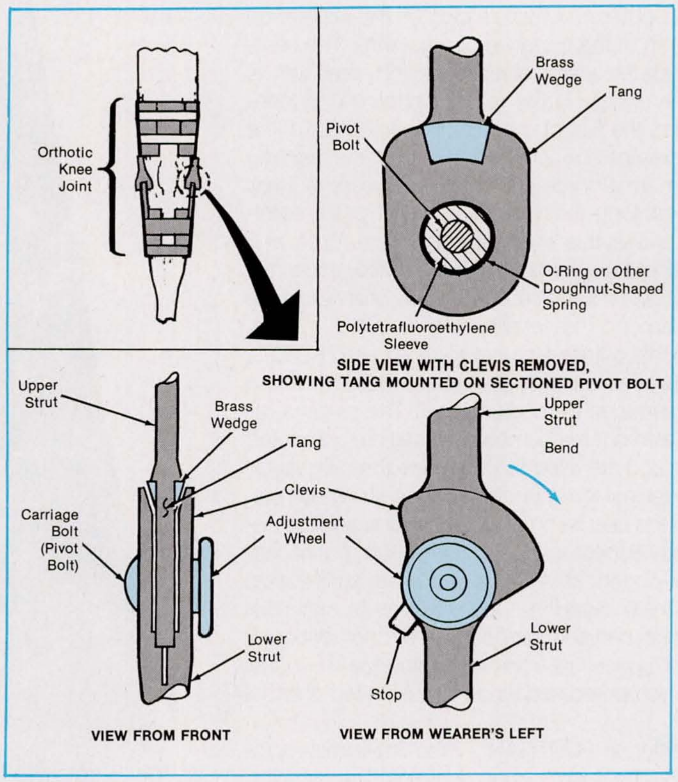
Marshall Space Flight Center, Alabama

A proposed orthotic knee joint would lock and unlock automatically, at any position within a range of bend angles, without manual intervention by the wearer. In contrast, a strap-on orthotic knee joint of the type in current use must be extended fully (that is, unbent completely) before it locks in place automatically: If, for any reason, the wearer fails to achieve full extension before applying weight, to the joint, the wearer could then fall. Furthermore, once the joint becomes locked, the wearer must unlock it manually before the knee can be bent again. This combination of features makes extension and flexion a cumbersome process and can discourage therapeutic exercise.

A joint of the type in current use is basically a tang-and-clevis joint equipped with a locking device that snaps in at full extension. The proposed joint would also include a tang and clevis, but it would lock whenever the wearer transferred weight to the knee and would unlock when the weight was removed. Locking could occur at any angle between a 45° knee bend and full extension.

In the proposed joint (see figure), an elastomeric O-ring or other doughnut-shaped spring would be placed between a pivot bolt of the joint and the tang. (A polytetrafluoroethylene sleeve between the bolt and the spring would reduce friction.) The spring would deflect when the wearer applied weight to the joint, so that the tang would move down a short distance within the clevis.

This relative motion would activate a friction lock by driving two brass wedges on the tang into a hard, radially serrated V-groove in the sides of the clevis. This would bind the joint so that the joint could take the load without folding. When the wearer removed the load, the spring would force the wedges up and out of the V-groove, and the joint would again be free to rotate.



This **Mechanism Would Lock** when the wearer's weight drove friction wedges into the V-groove defined by the right and left sides of the clevis. The mechanism would unlock when the weight was removed and the elastomeric spring forced the wedges out of the groove.

This work was done by Bruce Weddendorf of **Marshall Space Flight Center**. *For further information,* ***write in 37*** *on the TSP Request Card.*

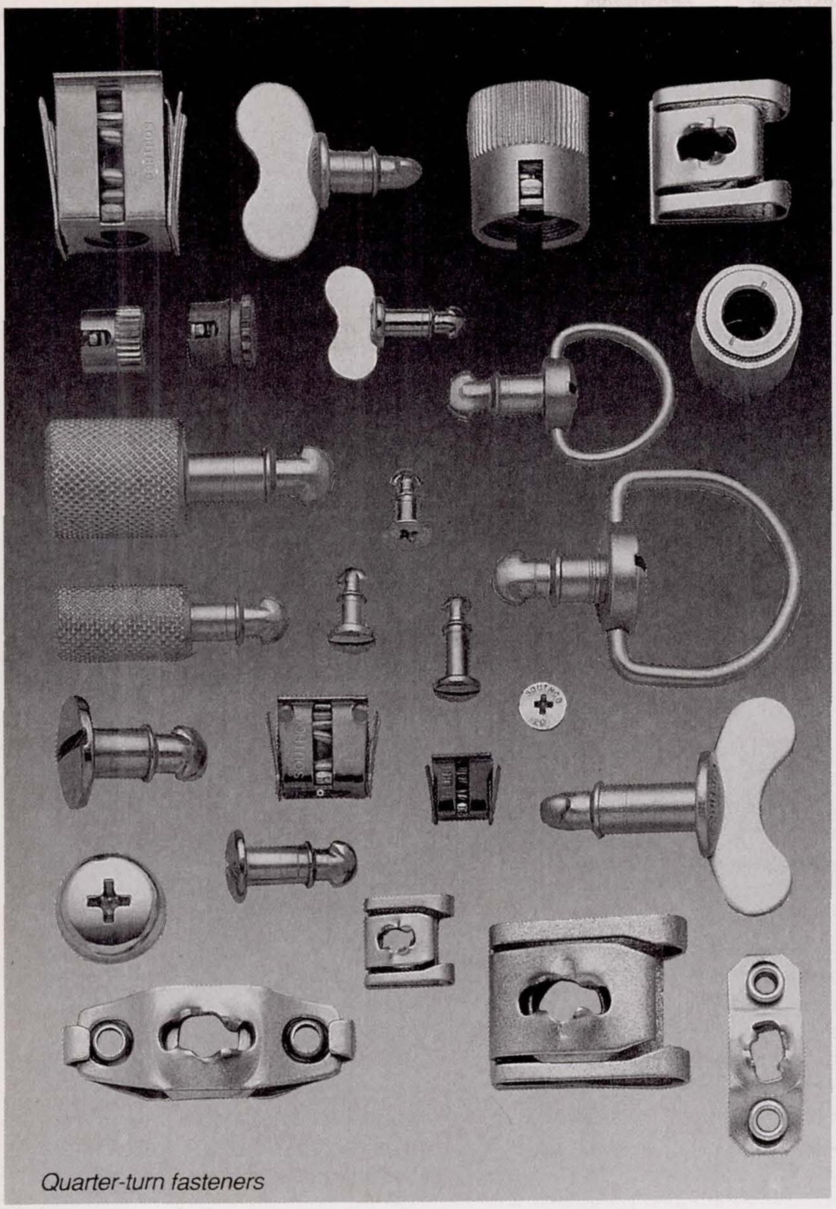
This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Marshall Space Flight Center [see page 20]. Refer to MFS-28633.

Estimating Sinusoidal Pressure Waves in a Pump Volute

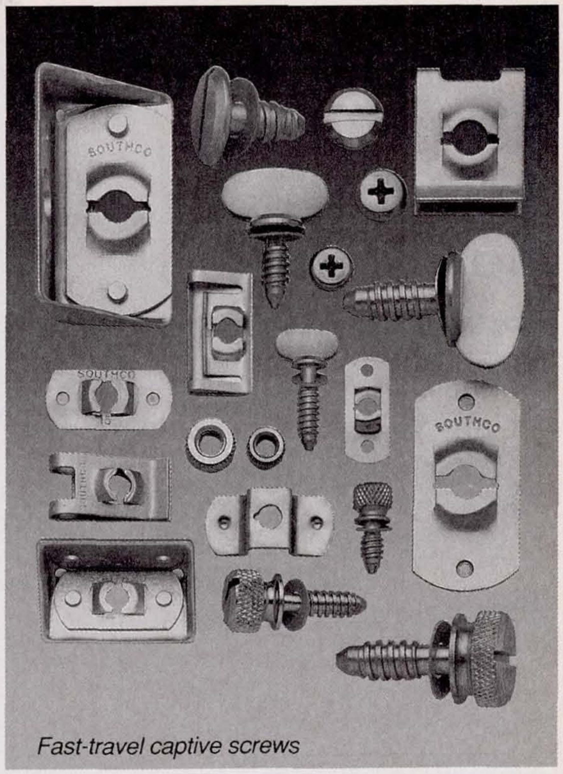
Sinusoidal fluctuations of pressure, which could excite structural resonances, are represented in closed form.

Marshall Space Flight Center, Alabama

A closed-form equation approximates the principal traveling-wave sinusoidal components of the fluctuations of pressure in the volute of a centrifugal pump (see figure). The equation has been incorporated into the Blade Vane Interaction Code (BVIC) computer program, which produces estimates for various pump speeds and various locations in the volute. The principal intended use of BVIC is in analysis of undesired interactions between the pressure field and the pump structure: If the



Quarter-turn fasteners



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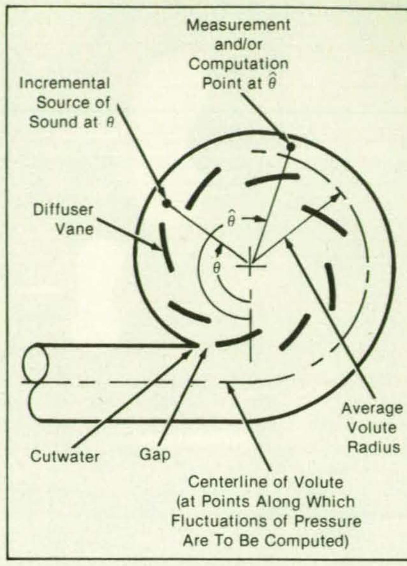
shape and frequency of any of the traveling-wave components computed by BVIC match the shape and frequency of a vibrational mode of the pump-discharge structure, then a severe resonance could occur and the pump could be damaged as a result.

The closed-form equation is derived from a simplified mathematical model of the generation and propagation of the pressure waves and of the geometry of the volute. The fluctuations of pressure are assumed to be sound waves (pressure waves) that are created when the wakes shed by the impeller blades impinge on the leading edges of the diffuser vanes. The volute is represented as a one-dimensional pipe, in which sound waves from all the diffuser vanes are added.

The pressure wave contained in the wakes is approximated as a traveling sinusoidal wave with an adjustable amplitude *A*. The interaction between this wave and the vanes is represented as a sinusoidal modulation of amplitude *B*, and the interaction regions around the vanes are taken to be smeared out, with interaction strengths as sinusoidal functions of position. With these approximations, the sound-source-density equations are easily combined and integrated along the volute to obtain the closed-form expression for the total pressure wave at a given addition or measurement location in the volute. This expression can be modified, if desired, by an exponential attenuation function of angular location that accounts for the effect of the gap (if any) between the first diffuser vane and the cutwater of the volute structure. The attenuation parameter (*k*), along with the amplitude and modulation parameters *A* and *B* respectively, can be determined by fitting computed relative pressure fluctuations to measured pressure fluctuations.

The expression represents five traveling-wave components, as follows:

1. A pressure wave of *m* lobes and frequency $m\Omega$ where *m* is the number of impeller blades and Ω is the frequency of rotation of the impeller. This wave travels forward at the speed of rotation; it is caused by the passing of impeller-blade wakes and would be present even if there were no diffuser vanes or cutwater.
2. A pressure wave of $m + n$ lobes that travels forward at $m(m + n)$ times the speed of rotation. It is caused by the modulation, by the *n* diffuser vanes, of the pressure wave described above. This wave is a manifestation of blade/vane interaction. This wave and the next one would not be present in a vaneless diffuser.



This **Typical Centrifugal-Pump Volute** is shown in simplified form to illustrate some geometric features relevant to the computation of sinusoidal fluctuations of pressure.

3. A pressure wave of $n - m$ lobes that travels at $m/(n - m)$ times the speed of rotation. The direction of travel depends on *n* and *m*. This wave is also caused by blade/vane interaction.
4. An acoustic wave that travels forward through the volute. The wavelength corresponds to that of sound at frequency $m\Omega$. The sound is caused by the impingement of the impeller-blade wakes either on the cutwater or on the leading edges of the diffuser vanes. This wave and the next one would be present even in a vaneless diffuser: the only requirement is that there be one or more stationary surface(s) in the pump upon which the impeller-blade wakes can impinge and thereby create sound.
5. An acoustic wave that travels backward through the volute. The wavelength corresponds to that of sound of frequency $m\Omega$. This wave is also caused by the impingement of the impeller-blade wakes on the leading edges of the diffuser vanes.

At certain critical pump speeds, some of these component waves interfere constructively in the volute, causing the sum wave to pick up energy as it travels along the volute. This effect is represented in the closed-form expression by terms with denominators that approach zero near the critical speeds.

This work was done by Roland J. Szabo and Juliet T. Chon of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information,* ***write in 36*** *on the TSP Request Card.* *MFS-29884*

Analyzing Acoustic Propagation in a Pump Diffuser and Volute

Reflections from impedance mismatches are taken into account.

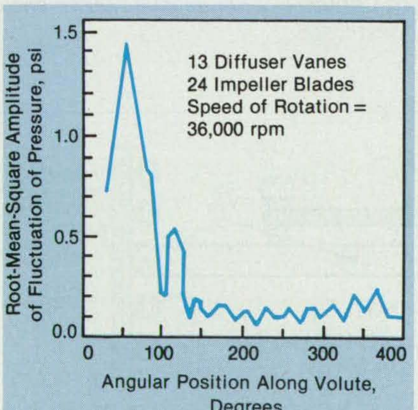
Marshall Space Flight Center, Alabama

A theory and computer codes have been developed for use in analyzing the propagation of the sinusoidal components of fluctuations of pressure (that is, acoustic waves) through the fluid in the diffuser and in the volute or discharge duct of a centrifugal pump. Such an analysis of propagation and the resultant fluctuations of pressure is an important part of an analysis of the fluid-borne contributions to stresses on the volute housing, the volute liner, and/or the discharge duct.

The mathematical model propagation and associated postprocessing routines are implemented in the computer codes, which are denoted collectively as "FLAPR-PUMP" and which include an updated version of the previously developed FLAPR computer code. In FLAPR, the propagation medium is represented as a concatenation of elementary volumes or elements, each characterized by a constant cross-sectional area, speed or sound, and density of fluid. The sound waves are assumed to propagate in only one dimension — along the elements. The acoustic impedance of each element is computed from its cross-sectional area and its resistance to flow. The partial transmission and partial reflection of waves at each interface between adjacent elements are computed in terms of the mismatch between the acoustic impedances of the elements. The contributions of all of the waves at a given point in the model are superimposed to obtain a history of pressure and velocity at that point. Phenomena that can be mathematically modeled in this way include the effects of the taper in the cross section of the volute, acoustic resonances of the duct, and complete details of the transmission and interaction of the many sound waves present.

The first part of the mathematical modeling process involves determination of the order in which the blades of the rotating impeller pass by the vanes of the stationary diffuser; this establishes the phases of the sinusoidal components of sound that are propagated into the volute. Sinusoidal pressure waves with these phases are used as boundary conditions at the input nodes of the mathematical model, which are those nodes that represent the entrances to the passages between the diffuser vanes.

The updated FLAPR computes the



The **Amplitude of Fluctuating Pressure** at the 12th harmonic of the rotational speed of a centrifugal pump, as a function of position along the volute, was picked out of the computed spectrum.

transmissions, reflections, and superpositions as indicated above, yielding a time-domain solution at each node in the model. For those nodes that lie in the discharge duct, the time-domain results are fast-Fourier-transformed into the frequency domain by use of the FFTAUTO computer code, which gives amplitudes and phases at each node over a frequency spectrum. Then the PICKPTS computer code is run to compile a list of the amplitudes and phases at each node for only the frequencies of interest, which are harmonics of the speed of rotation of the pump (see figure). Because the nodes of the mathematical model are placed in the volute at locations where measurements have been taken, and/or these nodes are input forcing nodes of a mathematical model of the dynamics of the pump structure, the results of these computations are ready for direct comparison with the measurements and/or for use as forcing functions.

This work was done by Juliet T. Chon and Roland J. Szabo of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information,* ***write in 35*** *on the TSP Request Card.*
MFS-29885

Viewport Wiper

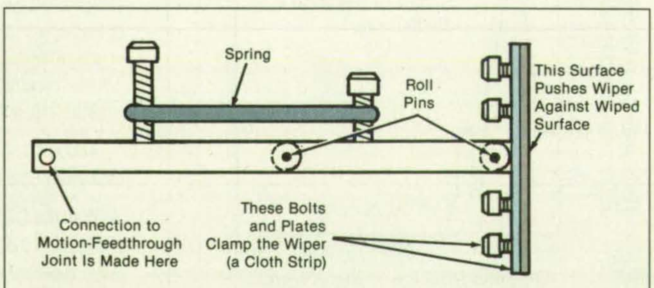
This mechanism helps maintain a clear view of a vacuum plasma spray.

Marshall Space Flight Center, Alabama

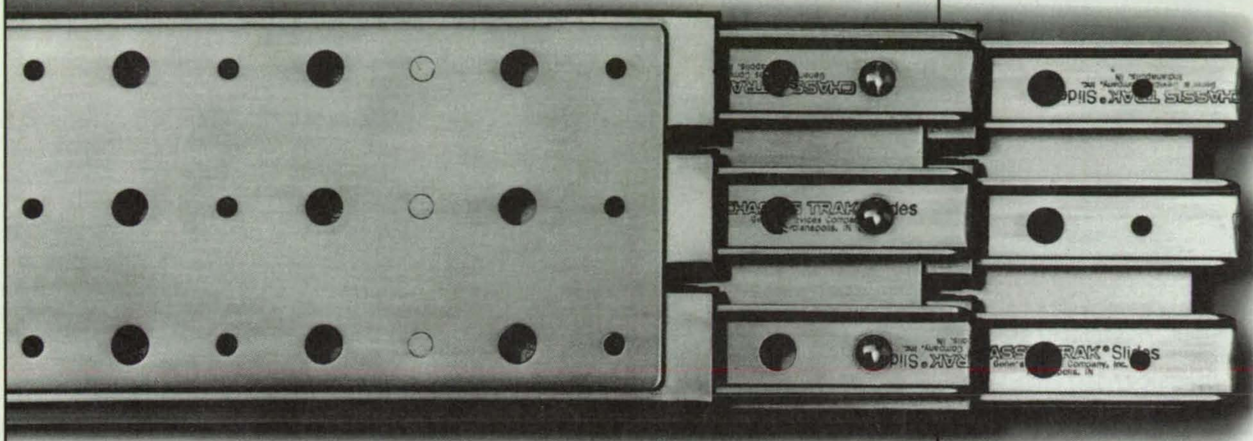
A wiper mechanism has been devised to remove accumulated powder from the viewport of a vacuum-plasma-spraying chamber. The deposition of powder on the viewport is an undesired side effect of vacuum plasma spraying: the powder must be wiped off the viewport from time to time to maintain the clear view that is necessary for monitoring the vacuum-plasma-spraying process.

The major part of the wiper mechanism is a wiper-arm assembly (see figure). The wiper is a replaceable cloth strip attached to a rectangular bar (on the right side in the figure). The left (in the figure) end of the wiper-arm assembly is attached to a vacuum-tight motion-feedthrough joint that is mounted on the wall of the chamber. The wiper is operated manually by use of this joint.

This work was done by William M. Davis, Ronald L. Daniel, Jr., and Christopher A. Power of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information,* ***write in 34*** *on the TSP Request Card.*
MFS-29898



This **Wiper-Arm Assembly** is actuated manually to remove accumulated powder from the vacuum side of the viewport.



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Pressure Seal for Frequently Opened Hatch

Improvements include more-secure mounting, redundancy, and better initial sealing action.

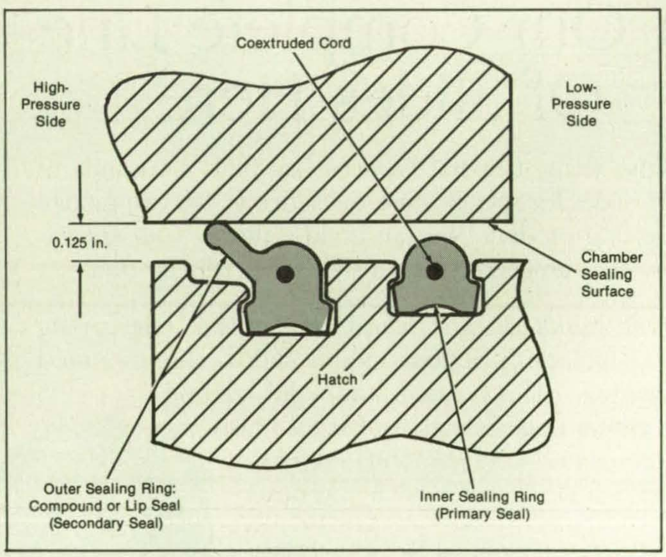
Lyndon B. Johnson Space Center, Houston, Texas

A pressure-assisted seal for a frequently opened hatch includes two sealing rings that are retained positively so that they are not pulled out during opening. The seal makes contact with the hatch well before the hatch starts to squeeze the rings; this feature extends the distance over which the seal becomes engaged.

The two sealing rings are retained in slots of T-shaped cross section (see figure). Entry points are provided on the slots so that the rings can be fed in. Once inserted, the rings are held securely. Each ring can be removed by first using a tool to pry it out at the entry point, grasping the protruding end, and pulling the rest out by hand.

The bottom (in the figure) surfaces of the rings are made concave to increase the precompression travel during closure; this helps to close gaps caused by warpage or machining irregularities. One of the rings includes a lip that extends outward for 0.125 in. (3.2 mm). The lip also helps to compensate for warpage, misalignment, and other imperfections in the sealing surfaces. It also minimizes the loss of gas during closure by deflecting inward and closing the gap. This action also helps the differential pressure force the hatch closed.

This work was done by Steven E. Kennedy and Joel M. Kramer of McDonnell Douglas for **Johnson Space Center**. *For further information,* ***write in 38*** *on the TSP Request Card.*
MSC-22055



Dual Elastomeric Rings provide redundant sealing. The lip on the outer sealing ring forms a pressure-assisted compound seal. A coextruded cord in each sealing ring helps keep the length of the ring constant.

Safety Harness for Work Under Suspended Load

Positive action protects against a heavy falling object.

Marshall Space Flight Center, Alabama

A safety device protects a worker under a suspended engine or other heavy load. The device (see figure) is mechanically linked with the load so that if the load should fall, the worker would be yanked safely away.

The worker wears a chest-plate vest with straps that cross at an eye on the back. A lower safety cable connected to the eye extends horizontally away from the worker to a nearby wall, where it is wrapped on a pulley and extends upward to a motion amplifier or reducer (if needed), which is shown here as a cable-and-pulley assembly.

An upper safety cable extends upward from the top of the motion amplifier, becomes horizontal between a pair of pul-

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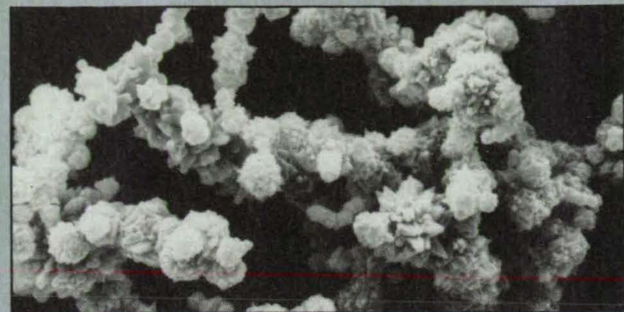
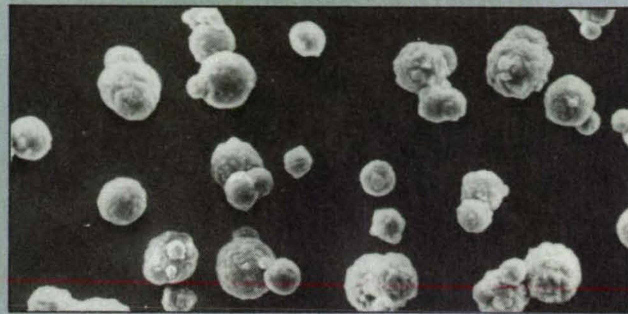
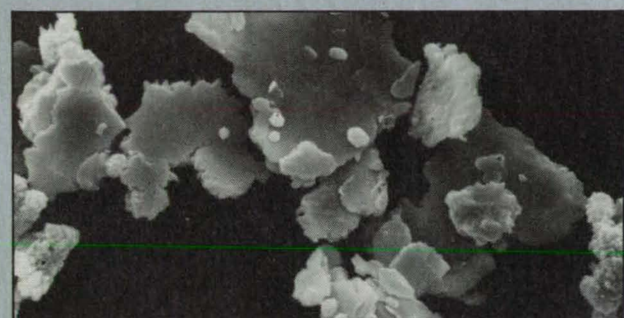


Inco Type T 287 Filamentary Powder, particle size (FSSS) 2.6-3.3 microns, apparent density 0.75-0.95 g/cc, relative surface resistivity 0.30 ohms per square (□).



Novamet Silver Coated Nickel Spheres, 15% Ag, 2.5 g/cc apparent density, particle size 10 microns, screen mesh 99%-250, surface resistivity 0.03 Ω/□.



Novamet HCA-1 Flake, screen mesh 98% minus 400, apparent density 0.90 g/cc, thickness 1.0-1.1 microns, surface resistivity 0.25 Ω/□.

Novamet Nickel Coated Graphite, 60% fully encapsulated Ni, apparent density 1.6 g/cc, particle size (FSSS) 100 microns, screen mesh 63% −150/+250, surface resistivity 0.3 Ω/□.

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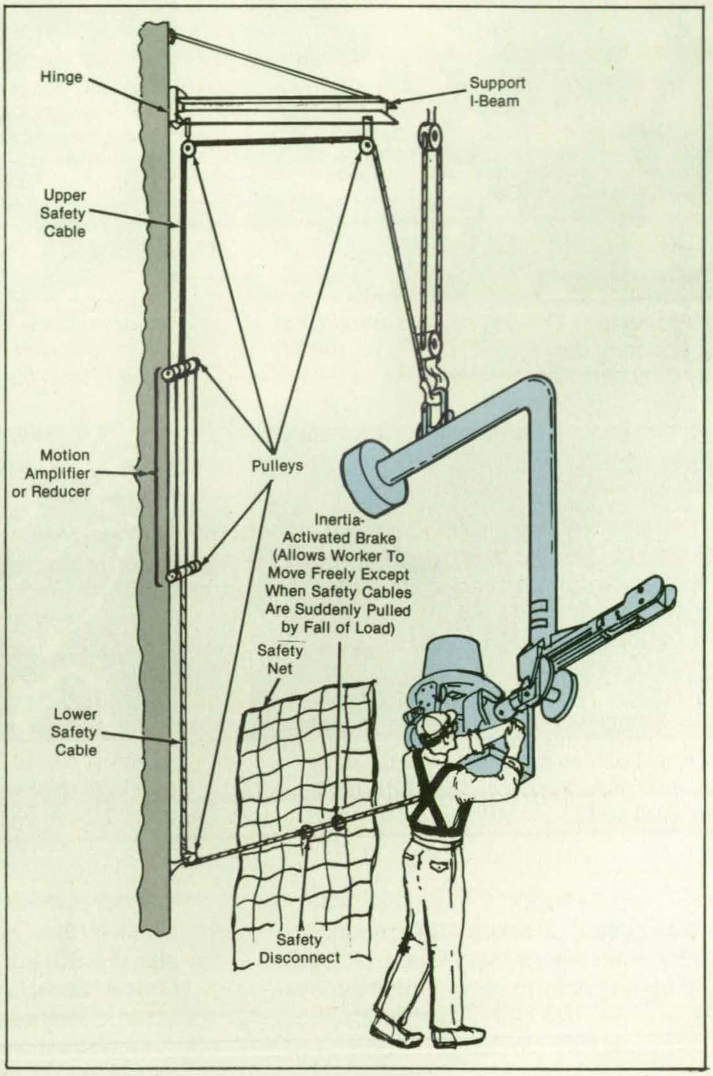
leys on an I-beam, then passes downward to its connection to the load.

Any downward motion of the load is passed to the upper safety cable, the motion of which is modified by the motion amplifier or reducer. The modified motion is passed onto the lower safety cable, which is thus made to pull the worker quickly out of danger. A net catches the worker, preventing the worker from bumping against the wall.

This work was done by Su Young Sunoo of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information,* ***write in 40*** *on the TSP Request Card. MFS-29893*



Safety Cables transform any sudden downward motion of the overhanging load into rapid sideways motion of the worker.

Modular Cooling Components

Simple mechanical connections facilitate assembly and disassembly.

Lyndon B. Johnson Space Center, Houston, Texas

Three modular heat-transfer components have been designed for use together or separately. Simple mechanical connections facilitate the assembly of these and related heat-transfer components into cooling systems of various configurations — for example, to cool laboratory equipment that is rearranged for different experiments.

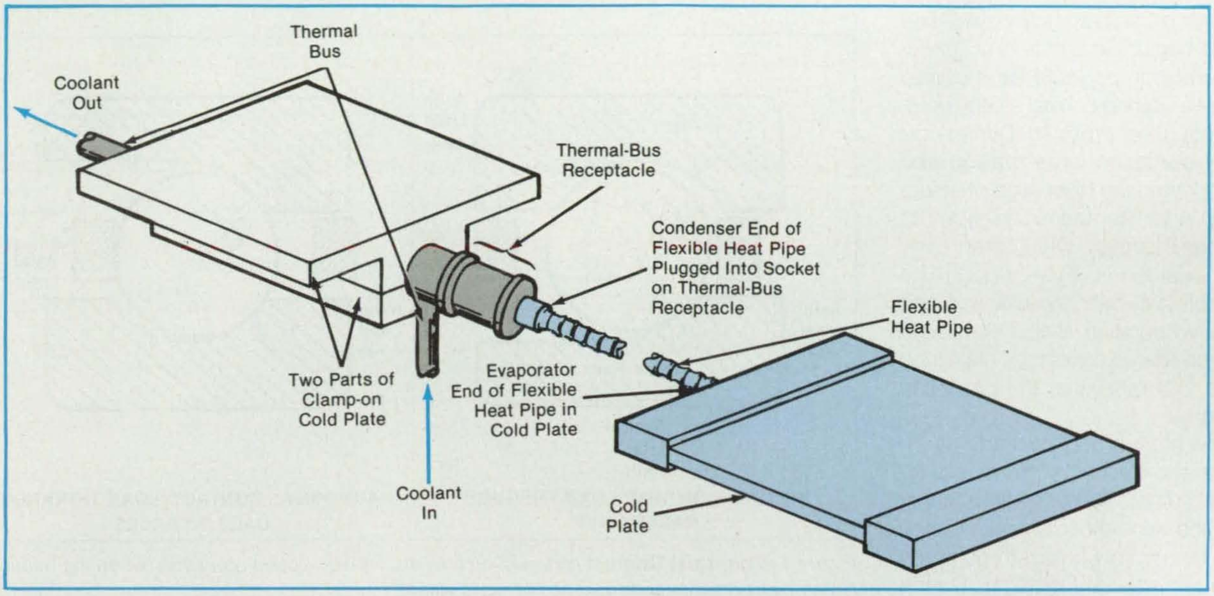
The three components are a clamp-on cold plate, a cold plate attached to a flexible heat pipe, and a thermal-bus receptacle. The clamp-on cold plate (see figure) can be moved to any convenient location for attachment of the equipment to be cooled by it, then clamped onto a thermal bus (a pipe carrying circulating coolant fluid). The heat from the equipment is conducted through the plate and into the coolant.

The thermal-bus receptacle is integral with a thermal bus. It includes the part of the thermal bus to which a clamp-on cold plate can be attached, plus a tapered socket into which the condenser end of the flexible heat pipe can be plugged. The thermal-bus receptacle includes a heat-pipe wick structure that uses the coolant in the bus to enhance the transfer of heat from the cold plate.

Like the clamp-on cold plate, the cold plate attached to the flexible heat pipe can be fitted, at a convenient location, with the equipment to be cooled, then placed near the thermal-bus receptacle. The condenser end of the heat pipe is a tapered plug and is inserted in the socket of the receptacle.

This work was done by G. Yale Eastman, Peter M. Dussinger, and John R. Hartenstine of Thermacore, Inc., for **Johnson Space Center**. *For further information,* ***write in 64*** *on the TSP Request Card.*

MSC-21495



These **Modular Components** can be use to assemble cooling systems of various configurations easily and quickly.

Partly Loading a Disengaged Ball Bearing To Reduce Wear

Leakage would be redirected to apply the requisite load.

Marshall Space Flight Center, Alabama

A ball bearing that carries transient axial loads at the beginning and end of operation of a turbopump would be modified to reduce wear during normal steady operation, according to a proposal. During normal steady operation (after startup and before shutdown), the discharge pressure of the pump is sufficient to cause hydraulic liftoff in other bearings, which then carry radial and axial loads. Even though this bearing is nominally disengaged or unloaded during steady operation, it is nevertheless subject to considerable wear, as explained below; this fact motivates the proposed modification.

During the startup and shutdown transients, when the discharge pressure is insufficient for hydraulic liftoff in other bearings, the balls in the transient-axial-load bearing are loaded by normal contact through the races (see left side of Figure 1). During

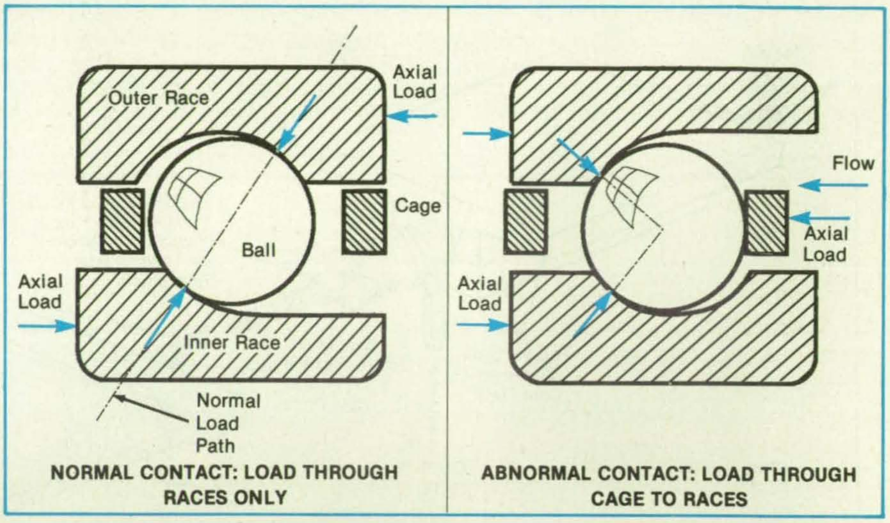


Figure 1. **Abnormal Contact** and swirling flow during high-speed operation (when the bearing is nominally disengaged) give rise to rapid wear.

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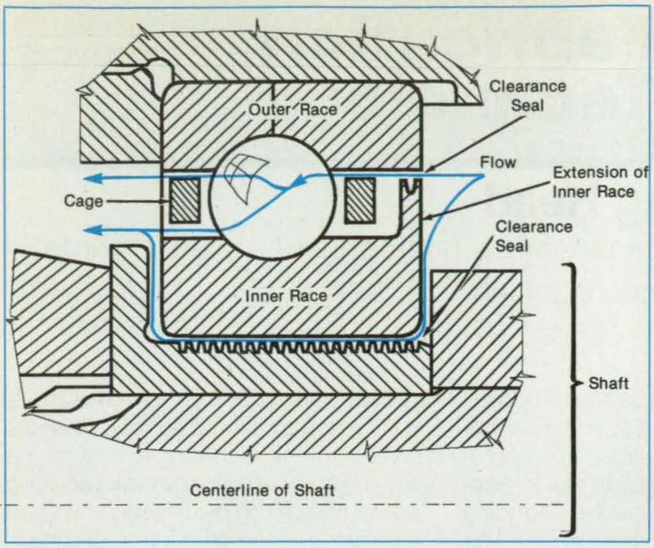

Figure 2. The **Modified Bearing** would be forced into normal contact by the flow of pumped fluid during high-speed operation.

steady high-speed operation, the balls are not loaded normally by the races, and the leakage flow of pumped fluid swirls around the balls in the cage pockets, making the balls spin rapidly. At the same time, the differential pressure across the cage pushes the cage downstream against the balls, forcing the balls into abnormal contact with the races and cage (see right side of Figure 1). Under this condition, the balls cannot roll in the normal manner. The resultant skidding at the contacts causes rapid wear of the balls and raceways.

The proposed modification is intended to reduce the influence of the fluid in making the balls spin and to apply enough axial load to ensure normal rolling contact with the races. The three main features of the modified design (see Figure 2) would be (1) a narrow-gap clearance (labyrinth) seal between the shaft and the inner race, (2) a narrow-gap clearance seal between the inner and outer races, and (3) an extension of the inner race to enlarge its upstream-facing area.

The enlarged upstream-facing area of the inner race would function partly as a piston, which would act in conjunction with the clearance seals. The upstream-to-downstream differential pressure on the piston would exert an axial load through the normal bearing load path. The resultant normal rolling contact would, in itself, reduce wear; it would also provide additional frictional torque that would counteract the flow-generated torque on the balls, thereby reducing wear further by reducing the speed of spin.

This work was done by Myles F. Butner of Rockwell International Corp. for **Marshall Space Flight Center**. *For further information* ***write in 53*** *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 [see page 20]. Refer to MFS-29874.

TECH BRIEF INDEXES

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"E" Heating Head

Two separate areas can be heated inductively for adhesive bonding in a single operation.

Langley Research Center, Hampton, Virginia

The "E" heating head has been developed to satisfy the need for a fast-acting and reliable induction heating device that is lightweight, portable, and easy to use in aerospace and military adhesive- bonding applications. In some applications — for example, in attaching "high-hat" stiffeners to aircraft panels — two separate bondlines must be heated concurrently. Previously, two separate heating heads were needed in such an operation. The "E" heating head inductively heats two separate areas (spots or seams) in a single operation.

The "E" heating head incorporates the principles and circuitry of the toroid joining gun, which can concentrate heat in a single local area through induction heating. The width and length of the "E" heating head can be configured to provide variously sized heat zones, depending on bonding requirements; for example, the figure shows an "E" heating head that has a 3 by 4.5-in. (7.26 by 11.43-cm) face.

The "E" heating head consists of a tank circuit and an "E"-shaped ferrite pole piece (magnetic core). The tank circuit includes a capacitor and an inductor coil. The inductor coil winds around the middle leg of the "E" core.

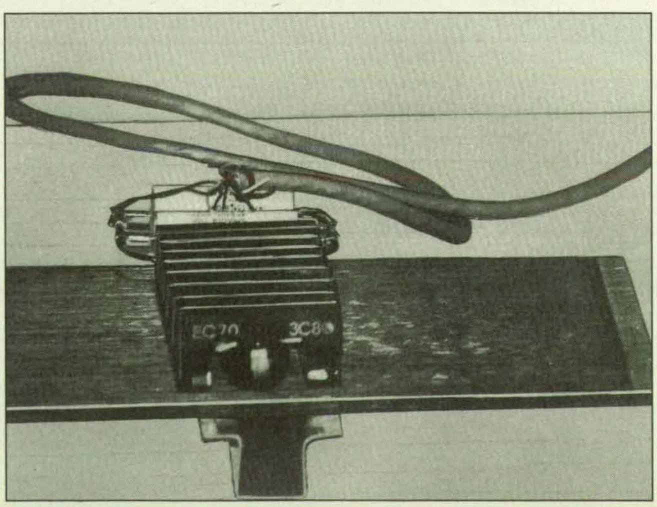
When an alternating current passes through the coil, an alternating magnetic flux is generated inside and around the coil. The flux is conveyed to the core, which focuses the magnetic flux to the two areas between the middle leg and two outer legs. When a conducting material (susceptor) is placed in the alternating magnetic field thus created, induced currents (or eddy currents) circulate in the susceptor, producing heat. When the panel or stiffener is a magnetic material, it is the susceptor. When both the panel and stiffener are nonmagnetic materials, a magnetic susceptor is positioned in the bond surface; heat is generated in the susceptor, and the adhesive in the bond is cured by the heat.

The "E" heating head is housed in a compact, portable container made of Bakelite® plastic that includes a handle, a power switch, and a power-input receptacle. When the "E" heating head is connected to an Inductron Corp. Torobonder T-1000 power supply, approximately 725 W of power are produced in the tank circuit. Resulting eddy currents generate sufficient heat to cure dual adhesive bond areas (spots or seams) rapidly in a single operation.

The lightweight, portable "E" heating head provides rapid, reliable heating of dual areas in any environment. It is well suited for flight-line and depot maintenance, and battlefield repair. Additionally, it may be useful in automotive assembly lines, inasmuch as "high-hat" stiffeners are used to strengthen automobile panels.

This work was done by Robert L. Fox, Robert J. Swaim, and Samuel D. Johnson of **Langley Research Center** *and Robert H. Coultrip, W. Morris Phillips, and Carl E. Copeland of Inductron Corp. No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or ex-



Dual Seams of a "High-Hat" Stiffener are bonded in one operation.

clusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center [see page 20]. Refer to LAR-14429.

Tank Made of Connected Cooling Fins

With inside welding, fins can be longer and more closely spaced.

Lewis Research Center, Cleveland, Ohio

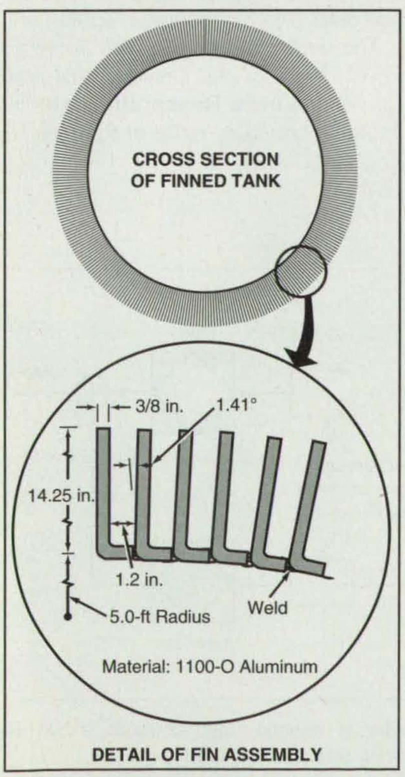
A new method of fabricating a fin-cooled tank requires half as many arc-welding passes as does the previous method and features more efficient transfer of heat. In the new method, the fins are integral parts of the tank structure.

Previously, to make such a tank, fins were individually welded to a plate that had been rolled into a cylinder. To assure the thermal continuity of each fin-attachment joint, this required a welding pass on each side of each fin at its root — a difficult procedure with long, closely spaced fins.

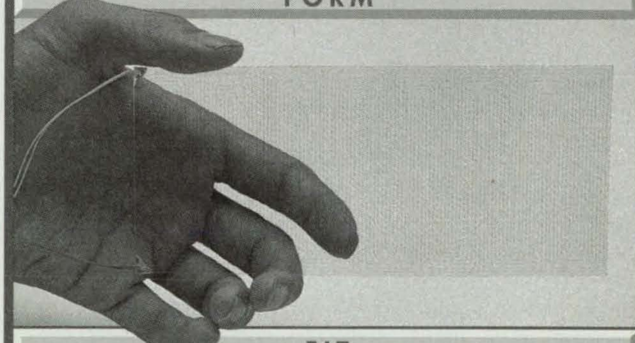
The new method requires only one welding pass per fin, and the pass is done on the unobstructed inside of the tank. Long L-shaped fin members are joined by welding the tip of the foot on each L to the bend of the adjacent L (see figure). The last fin member is joined to the first fin member to form a cylinder. The feet of the L's thus constitute the wall of the tank, and the legs of the L's are the fins.

The method has been proposed to build a tank of 1100-O aluminum 3.05 m in outside diameter with 256 fins, each 0.95 cm thick, 36.3 cm wide, and 6.4 m long. The tank holds water in which a radioisotope heat source is immersed before use. The water absorbs bremsstrahlung radiation from the isotope, and the fins dissipate the heat generated by the absorption.

This work was done by Donald F. Schultz and John J. O'Donnell of **Lewis Research Center**. *No further documentation is available. LEW-15115*



L-Cross-Section Segments are welded together to make a finned tank. The close spacing of the fins (about 3 cm) makes it difficult to gain access for conventional welding from the outside of the tank.



Subband and Transform Compression of Video Signals

Hierarchical coders offer good performance with limited computational complexity.

Lewis Research Center, Cleveland, Ohio

A class of hierarchical subband coders is being developed primarily for compression of image data at video rates. These coders offer good performance with limited computational complexity and with the flexibility inherent in subband decomposition.

The particular subband decomposition chosen for these coders appears to hide large quantitative errors effectively, largely because this decomposition occurs along two-dimensional spatial-frequency-domain boundaries that resemble the spatial-frequency-domain curves of constant sensitivity of the human visual system. These curves have been found to be approximately diamond shaped: thus, low-pass filtering for reduction of data ideally involves nonrectangular passbands.

The concept of decomposition along diamond-shaped boundaries is implemented in a subband coder that is a precursor to the present coders. This coder low-pass filters each image, followed by a two-subband decomposition of the remaining image, as shown in Figure 1. The diamond-shaped passband enables a quincunx downsampling of the original image, with an immediate reduction of sampling density by a factor of 2. The quincunx image is subjected to one further spatial-frequency-band separation, with the lowest band coded by the discrete cosine transform.

If high-resolution imagery is to be available to devices that have widely varying sampling rates, transmitted through channels of varying capacities, it may be necessary to band-limit a given image at several levels. Inasmuch as the diamond-shaped sensitivity contours hold over a broad range of spatial frequencies, it appears desirable to have available a hierarchy (symbolically, a pyramid) of spatial-frequency subbands. This is also true for temporally adaptive three-dimensional coding of image sequences. The form of the proposed decomposition is simply a generalization of that in Figure 1, with the inner square further decomposed recursively. While the pyramid need not stop at a particular level, a five-band decomposition has been found to be adequate for purposes of initial development.

The decomposition process can be understood by considering the transition from one level of the pyramid to one other. By limiting the image to the diamond-shaped band in the two-dimensional spatial-frequency domain, one can produce two images, the sum of which is the original image. Each of the resulting images is sampled at a rate equivalent to twice the necessary density (see Figure 2). Provided aliasing is excluded, each image can be decimated by a factor of 2 in a quincunx pattern. Should one wish to recombine to recover the original image, each subband can be interpolated to the original sampling rate and band-pass filtered before summing. Even when some aliasing exists in the decimated images, perfect-reconstruction filter banks can cancel aliasing and thus cancel errors in the final result.

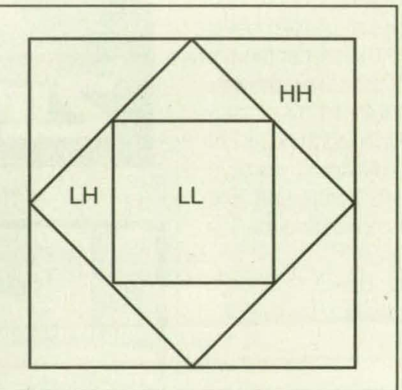


Figure 1. This **Subband Decomposition** is basic to a developmental class of high-performance, computationally efficient coders. The letters "H" and "L" denote subbands in the two-dimensional spatial-frequency domain that contain various high- and low-spatial-frequency components, respectively.

The two quincunx-sampled subband images can be thought of as being represented in the spatial-frequency domain on a rectangular grid rotated by 45° from the original. In this orientation, one can think of again low-pass filtering the low frequency image to separate bands as at the first level. The resulting decimated low-pass image is then sampled on a rectangular grip with decimation by a factor of 2 in each coordinate relative to the original. This process can be continued in a pyramid fashion, with successive low-pass images of smaller size, alternating between rectangular and quincunx grids.

One experimental pyramidal non-rectangular-subband coder of this type appears to perform well at intraframe bit rates of about 1.0 to 1.5 bits/pixel for color imagery. These rates would enable transmission of high-density television images at about 30 to 45 megabits/second by use of relatively inexpensive equipment.

This work was done by Ken Sauer and Peter Bauer of the University of Notre Dame for **Lewis Research Center** *For further information,* ***write in 5*** *on the TSP Request Card.*
LEW-15732

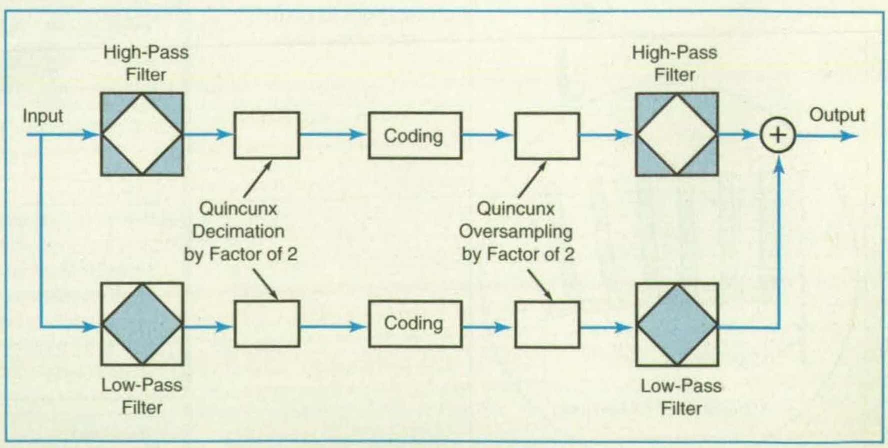


Figure 2. This **Single Stage of Decomposition** according to diamond-shape subbands, shown here schematically, is one of several in the pyramidal coding scheme described in the text.

Regenerable Iodine Water-Disinfection System

The service life of an iodination bed is lengthened.

Lyndon B. Johnson Space Center, Houston, Texas

An iodinated resin bed for disinfecting water can be regenerated to extend its useful life. In a demonstration, the resin bed was as biocidally effective after eight regenerations as it was when it was first operated. Presumably, it could have been regenerated many more times.

The regeneration system (see figure) includes a bed of crystalline iodine. Normally, the flow of water is diverted around the crystalline iodine and directed through the iodinated resin bed, where it absorbs a small amount of biocidal iodine before entering the potable-water system. When the iodine in the resin bed approaches depletion, the concentration of iodine in the effluent water drops to a low level. At this point, the flow of water is diverted through the crystalline-iodine regeneration bed. The water dissolves iodine in the regeneration bed and carries it to the resin bed, where it is absorbed.

When the iodine in the resin bed is fully restored, as determined by measurement of the concentration of iodine in the effluent, the flow through the regeneration bed is once again diverted around the regeneration bed. When the concentration of iodine in the effluent decreases below the minimum acceptable level, the regeneration cycle is repeated.

The regeneration concept was demonstrated in a small-scale prototype. The system was operated 24 hours a day for 114 days with an average iodine concentration in the effluent of 2.9 mg/L. The test was stopped after eight regenerations, but there were no indications that it could not have been continued indefinitely.

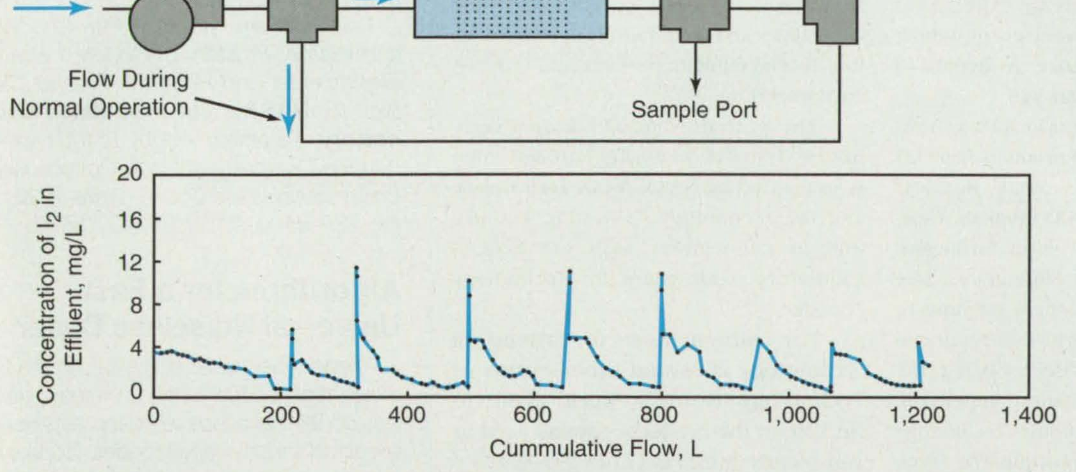
The first five regenerations, done at a rate of flow of 8.5 mL/min, produced spikes of 6 to 11 mg/L of iodine in the effluent, as shown in the figure. This rate of flow proved unnecessarily large, inasmuch as the high concentration was lost when the iodinated effluent was mixed with a much larger volume of water in a storage tank. Accordingly, the rate of flow during the last three regenerations was reduced to 3 mL/min, corresponding to a residence time of 0.8 min in the regenerator bed. This provided adequate iodine uptake and limited spikes to 4 to 5 mg/L.

The demonstration showed that regeneration increases the life of the resin bed, in terms of the amount of water disinfected, from only 60 L of water per cubic centimeter of resin to at least 500 L per cubic centimeter — and probably much more. At the end of the demonstration, the system was producing 4 mg of residual iodine per liter of water, just as it did at the beginning.

A further benefit of regeneration is that the regeneration bed can provide a highly concentrated biocide source (200 mg/ L) when needed. The concentrated biocide can be used to superiodinate the system after contamination from routine maintenance or an unexpected introduction of a large concentration of microbes.

This work was done by Richard L. Sauer of **Johnson Space Center** *and Gerald V. Colombo and Clifford D. Jolly of Umpqua Research Co. For further information,* ***write in 83*** *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 [see page 20]. Refer to MSC-21763.



Water Flows Through a Regeneration Bed of crystalline iodine during regeneration. At other times, the flow is diverted around the regeneration bed. Although the regeneration cycle was manually controlled in a demonstration, it could readily be automated to start and stop according to signals from concentration sensors.

Books & Reports

These reports, studies, and handbooks are available from NASA as Technical Support Packages (TSPs) when a Request Card number is cited; otherwise they are available from the NASA Center for Aerospace Information by calling (410) 859-5300, ext. 394.

Mathematics and Information Sciences

Some Practical Universal Noiseless Coding Techniques

A report discusses noiseless (that is, lossless) data-compression-coding algorithms, the performance characteristics of these algorithms, and practical considerations in the implementation of the algorithms in coding modules composed of very-large-scale integrated circuits. The report also has value as a tutorial document on data-compression-coding concepts. The coding techniques and concepts in question are said to be "universal" in the sense that, in principle, they are applicable to streams of data from a variety of sources. However, the discussion is oriented toward the compression of high-rate data generated by spaceborne sensors for lower-rate transmission back to Earth.

This work was done by Robert F. Rice of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Some Practical Universal Coding Techniques, Part III, Module PSI14,K+,"* ***write in 23*** *on the TSP Request Card. NPO-18833*

Optimality of Variable-Length Codes

A report presents an analysis of the performances of conceptual Rice universal noiseless coders, which are adaptive coders designed to provide efficient compression of data over a wide range of source-data entropies. A Rice universal noiseless coder includes (1) a predictive preprocessor that maps the source data into a sequence of nonnegative integers and (2) a variable-length-coding processor, which adapts itself to the varying entropy of the source data by selecting whichever one of a number of optional codes yields the shortest codeword.

The Rice coding algorithm is easily implementable. It codes data close to the entropy of the source data and can be extended to any entropy range. Each selectable coding option provided by the algorithm is optimized for a specific entropy range that is about 1 bit/symbol wide. For the purpose of the analysis, comparison is made with Huffman codes, which are widely known variable-length codes that are optimal under limited conditions. Each Huffman code is optimized to perform efficiently over a fixed, narrow range of source-data entropies.

This work was done by Pen-Shu Yeh and Warner H. Miller of Goddard Space Flight Center and Robert F. Rice of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "On the Optimality of Code Options for a Universal Noiseless Coder,"* ***write in 22*** *on the TSP Request Card. NPO-18834*

Algorithms for a Fast Universal Noiseless Coder

A report discusses some algorithms for a fast, high-performance universal noiseless coder that adaptively generates nearly optimal variable-length codes. Coders of this type are based on principles that are also discussed in the reports described in the accompanying articles, "Some Practical Universal Noiseless Coding Techniques" (NPO-18833) and "Optimality of Variable-Length Codes" (NPO-18834). The coding algorithms of the present report have been independently implemented in custom-made very-large-scale integrated-circuit coding modules by NASA's Jet Propulsion Laboratory and Goddard Space Flight Center in conjunction with the Microelectronics Research Laboratory at the University of New Mexico.

This work was done by Pen-Shu Yeh and Warner H. Miller of Goddard Space Flight Center and Robert F. Rice of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Algorithms for a Very High Speed Universal Noiseless Coding Module,"* ***write in 21*** *on the TSP Request Card. NPO-18835*

Electronic Components and Circuits

More About the PCIO Card

The PCIO user's guide presents additional information about the design, operation, and programming of the PCIO card, which was described in "Interface Circuit for Communication of Telemetric Data" (GSC-13547), *NASA Tech Briefs,* Vol. 17, No. 9 (September 1993), page 56. To recapitulate: The PCIO card is a programmable input/output interface-circuit card that enables a computer to transmit and receive high-speed, synchronous serial data and clock signals. It is designed to plug into an IBM PC-AT or compatible computer and to handle input and output of data in packet formats like those of telemetric data streams used throughout NASA and the aerospace industry.

This work was done by Thomas P. Flatley of **Goddard Space Flight Center**. *To obtain a copy of the PCIO User's Guide,* ***write in 96*** *on the TSP Request Card. GSC-13586.*

Tests of Advanced Nickel/Hydrogen Cells

Individual-pressure-vessel (IPV) nickel–hydrogen technology was advanced at NASA Lewis Research Center and under Lewis contracts with the intention of improving cycle life and performance. One advancement was to use 26 percent potassium hydroxide (KOH) electrolyte to improve cycle life. Another advancement was to modify the state-of-the-art cell design to eliminate identified failure modes.

This work was done by John J. Smithrick of **Lewis Research Center** *and Stephen W. Hall of Naval Weapons Support Center, Crane, Indiana. Further information may be found in NASA TM-105314 [N92-13483], "Effect of KOH Concentration of LEO Cycle Life of IPV Nickel-Hydrogen Flight Battery Cells — UPDATE II," and NASA TM-104384 [N91-22375], "Effect of LEO Cycling on 125 Ah Advanced Design IPV Nickel-Hydrogen Battery Cells — Am Update."*

Copies may be purchased [prepayment required] from the NASA Center for AeroSpace Information, Linthicum Heights, Maryland, Telephone No. (301) 621-0390. Rush orders may be placed for an extra fee by calling the same number. LEW-15389

Electrical Properties of Capacitors at High Temperatures

A brief report describes the results of experiments in which the capacitance and the dielectric loss of a glass, a metallized-polytetrafluoroethylene, and a solid-tantalum capacitor were measured at temperatures from 20°C to 200°C. Conclusions were drawn concerning the suitability of these capacitors for use at high temperatures; for example, in nuclear powerplants, aircraft, equipment for extracting geothermal energy, switching power supplies, and automotive integrated engine electronics.

This work was done by E. D. Baumann, I. T. Myers, and E. Overton of **Lewis Research Center** *and A. N. Hammoud of Sverdrup Technology, Inc. For further information,* ***write in 48*** *on the TSP Request Card. LEW-15677*

Physical Sciences

Development of Topographic Mapping With SAR

A report summarizes the development of an airborne interferometric synthetic-aperture-radar system (SAR) for topographic mapping. The basic principle of topographic mapping by use of interferometric SAR and the performance of an earlier version of the system were described in "Topographical Mapping With Synthetic-Aperture Radar" (NPO-16665), *NASA Tech Briefs*, Vol. 12, No. 9 (October 1988), page 39.

This work was done by Howard A. Zebker, Soren N. Madsen, and Jan Martin of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "The TOPSAR Interferometric Radar Topographic Mapping Instrument,"* ***write in 101*** *on the TSP Request Card. NPO-18746*

Study of Fuels for Hybrid Rockets

A report describes an experimental study of combustion and rates of regression of selected fuels for hybrid rocket engines. (A hybrid rocket engine is one in which an oxidizing fluid is injected into a combustion chamber that contains a solid fuel.) This study is part of a continuing effort to develop fuels with greater rates of regression and lesser dependence on shapes of fuel grains and to maximize potential specific impulse at low cost.

This work was done by Leon D. Strand, Robert L. Ray, Floyd A. Anderson, and Norman S. Cohen of Caltech for **NASA's Jet Propulsion Laboratory**. *To obtain a copy of the report, "Hybrid Rocket Fuel Combustion and Regression Rate Study,"* ***write in 102*** *on the TSP Request Card. NPO-18724*

Mechanics

More About High-Temperature Resistance Strain Gauges

Two reports present additional information on the electrical-resistance strain gauges described in "High-Temperature Resistance Strain Gauges" (LEW-15379), *NASA Tech Briefs*, Vol. 18, No. 1 (January 1994), page 50. These devices include 25-μm-diameter gauge wires of an alloy of 87 weight percent palladium and 13 percent chromium. The gage is temperature compensated with a 25-μm-diameter wire of platinum. For protection against oxidation at high temperatures, the gauges are covered, by flame spraying, with coats of alumina containing up to 1 weight percent of yttria or, preferably, containing 4 to 6 weight percent of zirconia.

This work was done by D. R. Englund and W. D. Williams of **Lewis Research Center**; *Jih-Fen Lei of Sverdrup Technology, Inc.; and C. O. Hulse of United Technologies Co. To obtain a copy of the report, "PdCr Strain Gauge,"* ***write in 19*** on the TSP Request Card. Further information may also be found in AIAA paper 91A-14462, "PdCr Based High Temperature Static Strain Gauge."

Copies may be purchased [prepayment required] from AIAA Technical Information Service Library, 555 West 57th Street, New York, New York 10019, Telephone No. (212) 247-6500. LEW-15518

Turbulent Flow in a Circular-To-Rectangular Transition Duct

A NASA technical memorandum describes experiments and analysis of experimental data pertaining to subsonic, turbulent flow of air in a duct that includes a gradual transition from a circular cross section at the inlet to a rectangular cross section at the outlet. This study is intended to support further research on the physics of flow, especially by providing a comprehensive set of data for the calibration and verification of (1) computer codes for simulation of transition-duct flows and (2) mathematical models of turbulence in flows in which the effects of curvature of streamlines are important.

This work was done by David O. Davis of **Lewis Research Center**. *For further information,* ***write in 32*** *on the TSP Request Card. LEW-15682*

Surface Fatigue Tests of M50NiL Gears and Bars

A report presents the results of tests of steels for use in gears and bearings of advanced aircraft. Spur-gear endurance tests and rolling-element surface fatigue tests were performed on gear and bar specimens of M50NiL steel that had been processed by vacuum induction melting and vacuum arc remelting (VIM-VAR). The report also compares the results of these tests with results of similar tests of specimens of VIM-VAR AISI 9310 steel and with results of similar tests of specimens of AISI 9310 steel that had been subjected to VAR only.

This work was done by Dennis P. Townsend of **Lewis Research Center** *and Eric N. Bamberger of General Electric Company. For further information,* ***write in 27*** *on the TSP Request Card. LEW-15741*

Materials

Core Losses in Three Alloys

A report describes an experimental investigation of the core losses and dynamic magnetic flux densities as functions of magnetomotive force ("B-vs.-H loops") of three soft magnetic materials under sine-wave voltage excitation at frequencies from 1 to 50 kHz and at temperatures from 23 to 300°C. The investigation was prompted by the need for data to design magnetic cores for efficient, lightweight power supplies that will operate in harsh environments. The reduction of mass of a core (for a given power) requires an increase in excitation frequency beyond the conventional 60-Hz powerline frequency. The reduction of overall mass of a power supply entails a reduction in the sizes of heat-dissipating components, with a consequent heating above the conventional ambient or near-ambient operating temperature. Most of the previously available data on the electrical and magnetic characteristics of soft magnetic materials pertain to operation at room temperature, with dc or 60-Hz excitation.

This work was done by G. E. Schwarze of **Lewis Research Center**, *W. R. Wieserman of the University of Pittsburgh, and J. M. Niedra of Sverdrup Technology, Inc. For further information* ***write in 88*** *on the TSP Request Card. LEW-15683*

New on the Market

Fluke Corp., Everett, WA, has released NetDAQ™, the first fully-integrated, analog-to-digital-to-Ethernet, PC-based **data acquisition and analysis system**. Two portable, 20-measurement channel models connect directly to a PC or can transmit data via Ethernet. The 2640A features a measurement speed of 100 RPS with 5½-digit resolution and 0.01% accuracy. The 2645A has a 1000 RPS measurement speed.

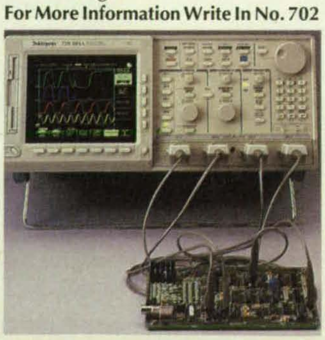
For More Information Write In No. 704

PATRAN® 3, updated **analysis software** from PDA Engineering, Costa Mesa, CA, features unique trimmed element analysis method (TEAM) meshless technology for simulation of product performance. P3/TEAM™ uses the original CAD geometry as the basis of the simulation, eliminating the modeling and meshing required in traditional finite element analysis and permitting optimization early in the design process.

For More Information Write In No. 708

Tektronix Inc., Beaverton, OR, has announced the industry's first 1 GHz **digital real-time oscilloscope** designed to streamline performance verification and debug digital circuits. The new TDS684 provides four channels of single-shot data capture, and is capable of sampling data at 5 GS/sec. simultaneously on all channels. Priced under $30,000, the TDS684 features 15,000 point record length.

For More Information Write In No. 702



The TouchStart™ TS-1 **capacitive palm button** from Scientific Technologies Inc., Hayward, CA, detects an operator's hand and actuates output relays at the slightest touch. It reduces the risk of repetitive motion injury by providing an alternative to mechanical palm buttons that often require substantial force to operate. Special circuitry prevents false triggering from radio frequency interface.

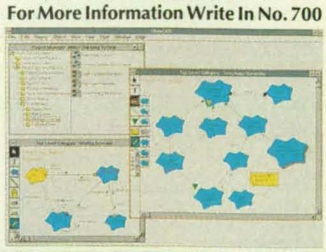
For More Information Write In No. 703

NovaComp Engineering Inc., Seattle, WA, has unveiled NovaLOAD, a **finite element analysis tool for applying non-uniform loads**. NovaLOAD eliminates the need for stepwise uniform approximation and tedious bookkeeping by converting non-uniform load distributions into discrete nodal input values in a user-defined format. Load distributions include scalar and vector quantities, pressures, fluxes, tractions, sources, and forces.

For More Information Write In No. 709

MultiQuest Corp., Schaumburg, IL, has introduced ShowCASE™, a multi-user **software engineering tool** that supports the Booch method of object-oriented design. Users can create graphical models of systems using smart diagramming tools that understand Booch semantics, then generate C++ code straight from the model. ShowCASE operates on heterogeneous networks of PC, Macintosh, and UNIX workstations.

For More Information Write In No. 700



Low-noise, high-performance **rotary-vane mechanical pumps** from Edwards High Vacuum International, Wilmington, MA, offer a universal motor, three gas ballast positions, and high-vacuum or high-throughput modes ranging from 3.9m³/hr. to 14.6m³/hr. All models feature a positive shut-off inlet valve and increased water vapor capacity.

For More Information Write In No. 713

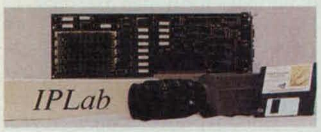
New on the Market

A series of **miniature harmonic drives** from HD Systems Inc., Hauppauge, NY, utilizes a patented S-tooth profile to provide twice the life, torque, and torsional stiffness of conventional systems. Measuring just 50 mm in diameter, they offer gear reduction ratios of 50, 80, and 100:1 and provide rated torques of 48 to 69 in-lbs. The drives feature zero backlash and positioning accuracy better than 1.5 arc-min.

For More Information Write In No. 711

The Image Explorer™ scientific **imaging system** from Signal Analytics Corp., Vienna, VA, captures and analyzes grayscale image data in both bright- and low-light. Priced at $6000, the system comprises a camera that integrates image data on-chip at video rates and a frame grabber. Included is *IPLab Spectrum* software, which automatically selects the best sample exposure time.

For More Information Write In No. 710



Harvard Thermal, Harvard, MA, has released PC3D, an easy-to-use, PC-based **thermal modeling tool**. Unlike similar tools adapted from structural analysis software, PC3D was designed for thermal analysis and easily incorporates temperature- and time-dependent properties, fluid flow, and radiation. A menu-driven, graphical, interactive environment provides model generation, execution, and post-processing.

For More Information Write In No. 706

The *Benchmark* line of **ultrasonic cleaning systems** from Branson Ultrasonics Corp., Danbury, CT, provides environmentally safe alternatives to CFC cleaning. The systems use coalescers or ultrafiltration units to extend the life of cleaning chemistries and cascade rinsing modules to minimize water use. Drying methods include hot air, nitrogen, infrared, capillary, and vacuum.

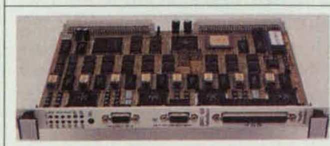
For More Information Write In No. 705

The Aurora™ **automated test systems** from ManTech Test Systems, Fairfax, VA, are designed to eliminate the long development times and high costs associated with automated test equipment design, integration, and debugging. Constructed with VXIbus architecture, the systems are available in portable, desktop, benchtop, and ruggedized models, including one with wheels.

For More Information Write In No. 701

Spectragraphics Corp., San Diego, CA, has introduced the TeamSolutions™ family of **collaborative engineering software**, featuring two programs that permit sharing of information between X- and/or 5080-compliant applications on network workstations, mainframes, or PCs. TeamConference™ establishes a real-time, interactive data link between conference participants all viewing the same screen image. TeamExchange™ enables users to create and distribute compound mixed-media documents from multiple databases.

For More Information Write In No. 707



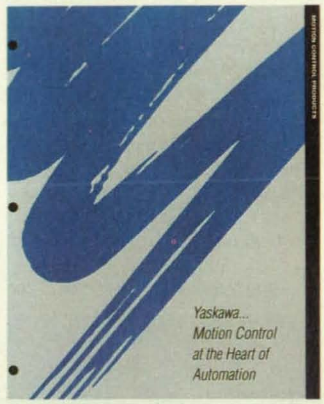
A **VME interface module** available from Pacific Avionics, Redmond, WA, employs a multiprocessor design to enable parametric testing. The ARINC-429 supports eight configurable parametric channels to receive or transmit, and eight low-speed "receive only" channels. The parametric channels handle variable word size, bit rates, voltage levels, and parity.

For More Information Write In No. 712

New Literature

Motion control products are showcased in a brochure from Yaskawa Electric America Inc., Northbrook, IL. Featured are all-digital AC servo drives and motors, new small sigma series AC servo drives, single-axis position controllers, single-axis motion controllers, inverter positioning systems, and DC servos.

For More Information Write In No. 716



Exergen Corp., Newton, MA, has published a 120-page reference to low-cost, **non-contact temperature measurement and control**. The pocket-sized handbook helps users apply advanced IR sensors to increase productivity, throughput, and quality while reducing costs. Included are operating principles, product specifications, and case histories of successful installations.

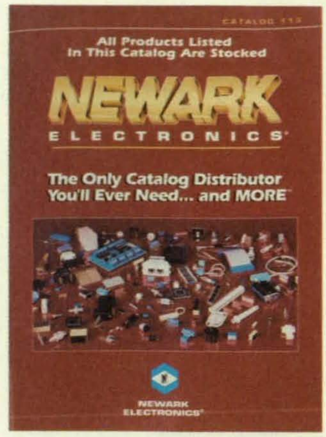
For More Information Write In No. 720

An engineering guide from the Avery Dennison Specialty Tape Division, Painesville, OH, assists in the selection of **pressure sensitive adhesive tapes**. It helps the user identify an application's specific environmental and substrate requirements and explains tape construction and adhesive types.

For More Information Write In No. 719

A 57-page **linear bearing products** guide from Del-Tron Precision Inc., Bethel, CT, describes ball bearing slide assemblies, crossed roller slides, table and rail sets, and multi-axis micrometer-driven positioning stages. A new low-profile crossed roller slide offers high-accuracy linear travel in a low cross-section bearing utilizing a single inner rail with a double V groove.

For More Information Write In No. 715



The 1552-page 1994 catalog published by Newark Electronics, Chicago, IL, contains more than 14,000 technical drawings and lists more than 120,000 **electronic and electrical components** from 285 manufacturers. This edition features more than 37 new vendors and 25,000 new products including surface mount, industrial control, and computer networking components.

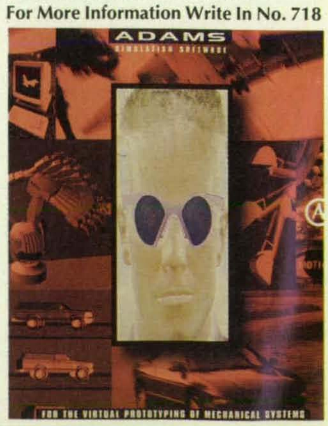
For More Information Write In No. 717

A catalog of **materials properties handbooks for design and analysis** has been released by CINDAS/USAF CRDA Handbooks Operation, West Lafayette, IN. Highlighted is the new, 900-page *Composite Failure Analysis Handbook* documenting current techniques, fractographic and material property data, and case histories. Other handbooks address aerospace structural metals, structural alloys, and damage-tolerant design.

For More Information Write In No. 714

Mechanical Dynamics Inc., Ann Arbor, MI, has released a brochure entitled *ADAMS Simulation Software: For the Virtual Prototyping of Mechanical Systems*. It introduces **mechanical system simulation technology** and describes how the ADAMS® products can be used throughout product development, from design concept to aftermarket behavioral reconstruction.

For More Information Write In No. 718



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AAS-fire protection technology; BS general science; MS chemistry. Chemistry, synthetic and analytical; environmental topics; ordnance; obscuration; operational safety; section head; chemical surety (detection, contamination avoidance, decontamination); consumer topics; proposal preparation (technical and cost); briefings and presentations; lab and field trials. Excellent writing skills.
Box number 44C

Technical instructor/trainer with background in PC hardware and the latest PC software: DOS 6.0, Windows 3.1, databases, communication, word processing and desktop publishing. Experienced in developing and implementing technical training courses. Additional experience with PC hardware maintenance, technical support and manual preparation.
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BSMET seeks full-time permanent engineering position in design or testing. Experience in original design, standards, and specification compliance. Courses: failure analysis, fluids, strength of materials, several computer courses. Strong commitment to learning as I believe education doesn't end in the classroom, but continues within the work situation.
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Results-oriented electrical engineering manager skilled in design, production and energy management. Expert in electronic controls and standards applications. Productive, experienced, and successful in integrating safety and cost controls. Analytical and creative problem solver. Proven negotiator and communicator. Effective in recruiting, training, and directing staff.
Box number 48C

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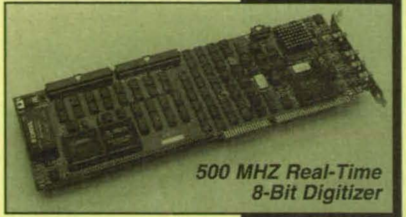

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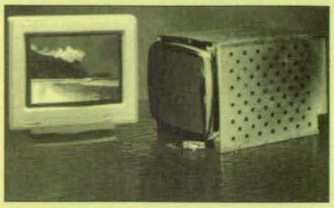

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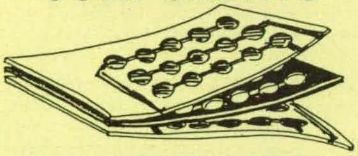

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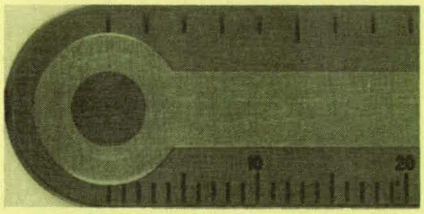

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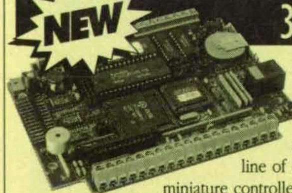

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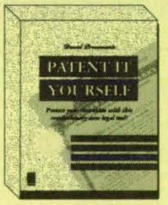

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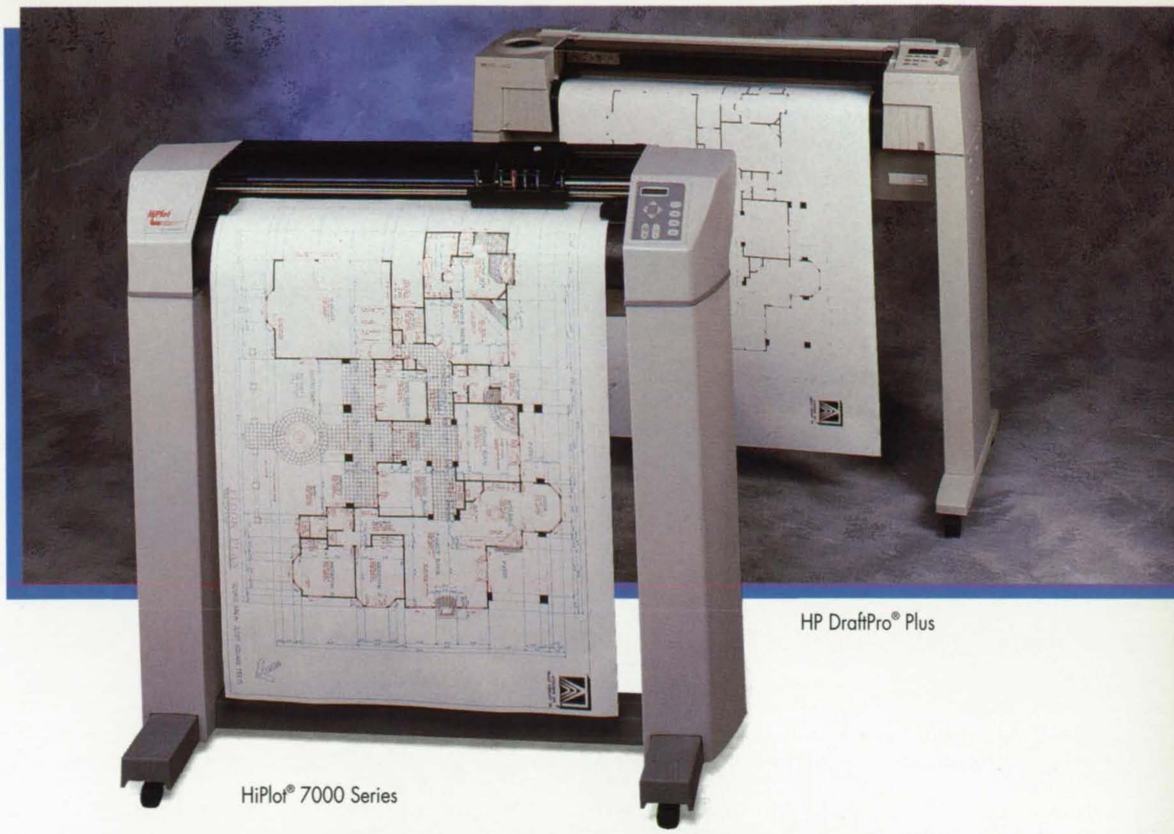

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