Dust Detection Experiment

Jupiter, like Saturn and Uranus, is a ringed planet. The rings of both Saturn and Uranus were discovered from Earth-based telescopic observations, but Jupiter’s rings are invisible to Earth-based instruments. In fact, their discovery hinged on a single photograph by Voyager 1, when the Sun’s rays backlit the dust particles and made them visible to Voyager’s sensitive cameras. “Particles” in Saturn’s rings range from dust to the size of houses, but Jupiter’s ring is believed to be composed entirely of dust particles.

The Galileo orbiter will carry an instrument designed to measure dust stream motion in the vicinity of Jupiter. The dust detection instrument will be mounted on the spinning portion of the orbiter.

Jupiter’s rings are composed of three elements: the visible ring composed of micron-sized particles which extends about 7000 kilometers broad and less than 30 kilometers deep; a faint disk extending from the inner edge of the visible ring all the way to the planet’s atmosphere; and a halo which extends more broadly and has a depth of about 100,000 kilometers.

What is the source of the particles in the rings? Current theory suggests that the micron-sized particles in the visible ring probably result from high-velocity impacts between small projectiles. Io’s volcanoes probably supply the force needed to inject large quantities of fine particulates into Jupiter’s plasma environment. If this theory is correct, there should be a “dust wedge” extending about 10° above and below the jovian equator out to about 700,000 kilometers (near the orbit of Europa). This is at a distance of about 10 jovian radii (Rj) from the planet’s center. Io is at about 5.9 Rj.

The dust detector will be able to measure the size distribution, spatial...
Sandia

As the Galileo orbiter swings past Jupiter for the first time in August 1988, listening for signals from the atmospheric probe, it will be bombarded by highly energetic particles in a severe radiation environment. If these particles affect the spacecraft’s sensitive electronics, changing their electrical responses, the mission could be dealt a major blow.

To assure the orbiter’s survival, several steps are being taken to protect its precious cargo, including the use of radiation hardened integrated circuits (ICs) scattered throughout the spacecraft. The design requirement demands that the chips be able to withstand a dose of 150,000 rads (150 krads)* with high reliability, taking into account the effects of radiation exposure both on the first swingby and during the satellite tour phase.

The orbiter’s electronics will consist of perhaps 21 microprocessors and 3500 memory chips. Since many of the important chips were not radiation hardened, JPL turned to Sandia National Laboratories in Albuquerque, New Mexico, to develop the necessary radiation hardening processes and chips.

Sandia, operated by Bell Telephone’s Western Electric for the U.S. Department of Energy and other federal agencies on a nonprofit basis, plays a major role in national defense and energy. Sandia’s Center for Radiation-Hardened Microelectronics (CRM) focuses on creating radiation hard technologies, generating IC designs, producing parts when there is no industrial source, and transferring the designs and technology to private companies. Galileo’s needs could not be met by industrial suppliers who deal in large-quantity orders for high-demand parts that do not meet Galileo’s radiation-hardening requirements.

“Genetics and microelectronics are probably the two most dynamic technologies today. A generation of technology may be only three to five years old before there are new developments,” says CRM’s chief Bob Gregory. “We want to maintain our position as the country’s leader in developing radiation hardened technologies and making them available to users. The severity of the radiation levels are not much different now than they were in the mid-1960’s—what changes is the steady increase in complexity of the integrated circuits.”

As an example, the new random access memory (RAM) chip designed by CRM for Galileo can sense, store, and retrieve 16,384 bits of information, compared to only 1024 bits for the previous generation of radiation hardened RAMs. The new chip contains more than 100,000 transistors and continues to function after one million rads (one megarad) total dose exposure. And its size is only $0.6 \times 0.4$ centimeters.

As such parts get smaller and smaller, they are affected not only by ionizing radiation but also by upsets due to collisions with energetic particles such as cosmic rays and trapped heavy ions. These events are referred to as Single Event Upsets (SEUs). It was recently determined after a review of Voyager and Pioneer data that there is a significant number of potentially dangerous oxygen and sulfur ions in the Jupiter environment. This environment would cause significant disruption in the orbiter’s attitude control (AACS) electronics. Once again, Galileo turned to Sandia to develop replacement parts immune to both ions and ionizing radiation.

Design and development of a new IC requires anywhere from six weeks to two years. “When JPL asked Sandia to design the new chip needed for Galileo’s attitude control system, the task involved demanding requirements, small quantities, and a short time scale,” says Gregory. “We consider our work for Galileo very challenging and important. It has high visibility and support at the top levels of Sandia.”

Sandia’s task, begun in August 1983, is to redesign, produce, and deliver the new parts by September 1984, replacing high-speed bipolar technology with slower but SEU-immune CMOS (complementary metal oxide semiconductor) chips. Design is complete, and chips should be available for testing in mid-May 1984.

From the Project Manager

Continued from page 1

deliveries and hardware problems, as well as reassessment of the time required to conduct certain operations based on the operating experience to date. Flight acceptance is now scheduled for early 1985. Even with the change in schedule, we have a comfortable margin for burn-in and the incorporation and checkout of the Single Event Upset fixes before shipment to Florida in January 1986.

—John Casani

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*A rad is a unit of radiation energy absorption. A chest x-ray dose is about 0.025 rad, while a whole body dose of about 1000 rads is usually fatal to humans.
Dust Detection

Continued from page 1

extent, and orbital trajectories of the sub-micron-sized dust particles and to determine if there is indeed a dust wedge.

Jupiter's satellites are continually bombarded by meteoroids and dust particles—both interplanetary material and debris from within the jovian system. By measuring the dust flux near the satellites, much can be learned about the satellites' surface properties in relation to the dust flux. Spatial and temporal variations, as well as directional asymmetries in the dust flux, will give clues to the reasons for albedo (reflectance) variations of the satellites.

As meteoroids impact the surface of our moon, surface material flies up and is ejected from the impact crater. A small percentage of this ejecta receives enough velocity from the force of the impact to actually escape from the moon's gravity. Similar ejection processes probably occur on Jupiter's satellites, contributing to the dust environment around the planet. During close encounters with the satellites (less than 1000 kilometers from the surfaces), the dust detector will be able to detect such ejecta particles. From this measurement, scientists can estimate the total meteoritic influx on the satellites.

The dust detector will measure the electrical charge on the larger dust particles entering the instrument. By correlating these measurements with measurements of the flux of high-energy particles, one can study how the dust grains become charged. Measurements of particle velocities will provide information on the frictional interaction with the plasma, while the measured particle mass distribution will give information on the source and transport mechanisms. If the dust particles carry an electrical charge, they may co-rotate with Jupiter's magnetic field. Electrostatic charges on the dust particles are of particular interest. At Saturn, for example, electrostatic levitation is thought to be the cause of the mysterious radial spoke features in the rings, as fine dust particles are elevated above the ring plane by static electricity along the planet's magnetic field lines.

If large, low-density "fluffy" aggregate particles become strongly charged, the electrostatic force can literally blow them apart, creating a swarm of micrometeoroids. A group in Heidelberg has observed these swarms in the Earth's magnetosphere with their HEOS experiment. A similar fragmentation is expected to occur when "fluffy" interplanetary particles enter Jupiter's magnetosphere.

The instrument is a modified version of the impact plasma micro-

meteoid detector successfully flown on the HEOS-2 satellite. It consists of a multicoincidence detector and associated electronics, and a microprocessor to control the instrument's operation and process the data for telemetry to Earth.

Positively or negatively charged ions entering the sensor are first detected by the charge that they induce when they fly through the entrance grid. This charge signal will only be evaluated if the ion subsequently impacts the impact plasma detector. Dust particles—charged or uncharged—are detected by the plasma produced during the impact on the gold target of the sensor. After separation by an electrical field, the ions and electrons of the plasma are accumulated by charge-sensitive amplifiers, thus delivering two coinciding pulses of opposite polarity. The pulse height, or total charge, is a function of the particle mass times velocity. The rise time of the pulses depends only on the particle's speed. From both the pulse height and the rise times, the mass and impact speed of the dust particle can be derived. Redundancy in the instrument increases the accuracy of the measurements.

The instrument sensor weighs 2.3 kilograms and requires 0.3 W. The electronics weigh 1.8 kilograms and require 1.5 W. The sensitive area of the sensor is 1000 cm², and the unobscured field of view is 140°. The instrument will be able to detect particles with mass from $10^{-16}$ g to $10^{-6}$ g and charges from $10^{-14}$ Coulomb to $10^{-12}$ Cb (positive) or $10^{-10}$ Cb (negative). It will be able to detect as many as 100 impacts per second.

The principal investigator is Eberhard Grün of the Max Planck Institut für Kernphysik (MPIK) in Heidelberg, Federal Republic of Germany. He is aided by an international team of six co-investigators. The instrument was designed and built by the Space Electronics Group at MPIK with the help of outside contractors ARGE PEES, Wald Michelbach, and WFG Fischer GmbH, Stuttgart.

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Note to Galileo team members at JPL: To cut down on distribution costs, The Galileo Messenger is now being distributed to you through your Galileo Division Representative.
Semiconductors

Fifty years ago a project such as Galileo belonged to the realm of “speculative fiction”—it couldn’t be done. Perhaps no advance in technology has had more impact on what we can do in space than has the field of microelectronics—the miniaturization of electronic circuits, especially for use in computers.

The development of the transistor in 1948 provided a small, low-power device to control electrical signals for digital systems. Transistors are made of solid materials such as silicon or germanium whose electrical properties lie somewhere between conductors and insulators: they are semiconductors. Exploiting the characteristics of the semiconductors, such as the positive (p) and negative (n) regions that could be created within them, led to the development of integrated circuits (ICs)—circuits with many transistors, resistors, and diodes on a single “chip” of semiconducting material.

In large scale ICs, tens of thousands of transistors and their interconnections are manufactured simultaneously on a silicon chip perhaps one-quarter of an inch square and 25 mils thick (a mil is a thousandth of an inch). The size of the features on the circuit are decreasing: in 1975, the structural features were about 10 microns; today, they approach the 2-micron size. (A human hair is about 75 to 100 microns in diameter.) The decrease in feature size allows an increase in the number of features, such as transistors, that can be packed onto a single chip, thus increasing the complexity of the functions that can be performed.

Semiconductor devices are made by introducing impurities into pure silicon to affect the electrical properties, a process called doping. Doping with an element that results in an extra electron in the atomic structure gives an n-type semiconductor (for the negative charge of the electron). Doping with an element that creates a deficiency of one electron, or a hole in the lattice of the silicon’s atomic structure, gives a p-type semiconductor (the hole has a positive charge and can carry an electrical current). A semiconductor may have “wells” of either type, or both, depending on its functions.

Semiconductors to be used in space run the risk of radiation damage, in which high-energy particles may alter the atomic structure by adding an electron or creating a hole. Galileo’s journey into Jupiter’s sizzling radiation belts require that its computer chips be radiation hardened—able to perform even after a radiation dosage of $1.5 \times 10^5$ rads.

Radiation hardness is built into the chips in several ways: chip designs and higher voltages strive to make circuit operations relatively insensitive to radiation-induced shifts in operating parameters such as threshold voltages; synchronous circuits, driven by a master clock producing a constant stream of control pulses, are preferred over asynchronous circuits since they are less affected by extraneous signals and processing variations; leakage paths caused by ionizing radiation are limited by placing highly conductive guard bands around the oppositely charged transistors. In the actual processing steps, extreme cleanliness, thin oxides, and reduced processing temperatures are radiation hardening techniques.

An IC is complex in both the topography of its surface and its internal structure. It has a three-dimensional architecture made up of many layers of detailed patterns. Computer-aided design (CAD) is an important tool in designing a new IC. A library of standard “cells” is available for various functions, and these cells are modified, layered, and hooked together as needed for a specific function. Computer analyses are used to troubleshoot during the design process to minimize later production and performance problems. Designers maintain close contact with both the engineers who...
A wafer containing many die is inspected by a processing science technologist. A technician holds a packaged semiconductor chip.

will use the chip and the processors who will manufacture it. The design phase may take several work-years.

Once the design is completed and approved, a set of plates, called photomasks, are produced. These are the masters for producing the chips. A single layer of a circuit is produced many times on the mask in a "step-and-repeat" pattern. Currently, photolithography is used to create the masks with high-resolution cameras, but new technology for electron beam lithography will allow the pattern to be printed on the mask directly from the computer. The chips manufactured by Sandia for Galileo's attitude control system require nine masks.

Chip production starts with the growth of a single large crystal of silicon, perhaps three to four inches in diameter and several feet long. The crystal is cut into wafers, typically two to four inches in diameter and half a millimeter thick, and the wafers are polished. An oxide layer is then grown on the surface of the silicon wafer as an insulator and as a mask for the doping processes. The microelectronic circuit is built up layer by layer, using the masks in a photogravure technique. Perfect alignment is required as each layer is added. The doping occurs in this stage. The final masks include a metal mask to form the interconnections between the circuits and the bonding pads for wires which will connect the finished circuit to other circuits. After extensive testing to weed out defective circuits, the wafer is sawed into dice, or chips. The chips are mounted within a cavity in a ceramic package and fine wire leads are connected from the bonding pads on the dice to the electrodes of the package. The packages are then sealed and readied for final testing.

Galileo is using complementary metal-oxide semiconductors (CMOSs). CMOS ICs have both p-channel and n-channel MOS transistors. These semiconductors cut power consumption, an important point for a spacecraft that must generate and regulate its own power.

Special thanks to . . .
E. Graham (N5HH), B. Gregory, T. Gavin, L. Wright

WWWWh* *(Who, What, Where, Why, and How)

Q: How do we know when to launch Galileo from the Earth so that it not only reaches Jupiter at the right time, but also encounters the Galilean satellites properly?

A: Celestial mechanics deal with how heavenly bodies move and the complexities involved with flying to the planets and encountering them at certain times and places in space. Galileo's Science and Mission Design Team has the challenging task of calculating how and when to launch Galileo so that it satisfies the many scientific objectives. Currently, there are three possible satellite tours. As the launch date gets closer, the specific tour to be flown will be selected.

Note: In the October 1983 issue's article on Single Event Upsets, please note that by themselves, lo's volcanoes do not impart enough velocity to particles to cause them to escape from the satellite.

B. G. Lee
Meet the Team

The Galileo Project can be glad that a young native of St. Louis, Missouri heeded Horace Greeley's advice to "Go west, young man," for Matt Landano has made valuable contributions to the design of the Galileo spacecraft.

Matt joined JPL in 1969 and gave four years to the Viking spacecraft design before turning his attention to Voyager. In 1978 he became supervisor of the Outer Planets Spacecraft Design Group, and in the fall of 1982 he was appointed Galileo's third Spacecraft System Engineer, following Ron Draper and Chris Jones.

"It has been very challenging to develop a spacecraft design for such an ambitious mission and to keep the design on track despite all the redirections. I feel confident we will have a spacecraft that meets the mission requirements," Matt says. "We have a unique spacecraft configuration that has never been flown before: dual spin with long flexible booms, nine science instruments and an entry probe. Sophisticated attitude control is necessary for pointing the science instruments and antennas to provide the high data return at large distances. There have been a number of new hardware and software developments, particularly in the attitude control and data system designs. It's been exciting to be involved with such an advanced design spacecraft."

Matt's team is now actively supporting the system design verification activities as both the Development Test Model and the flight spacecraft undergo integration and test. They continue to be deeply involved in the single
Meet the Team  Continued from page 6

event upset (SEU) effort and in the development of flight software, especially in the areas of sequencing and fault protection, both critical to the proper, autonomous functioning of the spacecraft far from Earth.

Like a lot of other people, Matt had great interest in space in the 1960's, but never suspected where this might lead him. After receiving B.S. and M.S. degrees in electrical engineering from California State University at Los Angeles, Matt did missile work at General Dynamics and McDonnell-Douglas until he joined JPL.

Matt, his wife Angeline, and teenaged daughters Lisa and Karen live in Glendale. They are active in supporting hospital functions and their church, and enjoy going to the mountains and deserts. The whole family has taken up skiing. At home, Matt likes to garden, and avidly reads mythology, particularly Greek and Roman.

Static Test

The Development Test Model of the Galileo spacecraft has completed 14 weeks of static test as part of the structural validation activities. The tests are required of any structures that will fly in the Space Shuttle. There are 26 tests in this series, conducted in JPL's Static Test Tower.

For these tests, engineers first calculate the maximum accelerational loads (G's) that may occur during Shuttle launch. These loads are then simulated in the DTM structure with hydraulic rams. Resulting stresses within the structure are measured by strain gages. A microcomputer control system is programmed to monitor the strain gages and protect the structure from excessive loads. The loads induced in test are 20 percent greater than expected to occur during launch. Data from the tests will be used to correlate predictions made in mathematical analysis of the structure during the design process.

Test and Integration Status

As of late November 1983, all flight hardware for the Galileo orbiter had been tested with the exception of the X/S downconverter, the star scanner ceramic tubes, and the flight radioisotope thermoelectric generators. Major updating will be required for fuses, random access memory (RAM) chips, microprocessors, and radiation hardening. Phased software deliveries have allowed subsystem integration to proceed to date, and major software deliveries will occur in January 1984 for the attitude and articulation control subsystem (AACS) and April 1984 for the command and data subsystem (CDS) and additional AACS. Electrical integration of subsystems was completed in October with significant liens due to late hardware and software deliveries. All flight subsystems have been integrated except the retropropulsion module (RPM), antenna system (SXA), and spin bearing assembly (SBA). Additional work is required to complete the electrical integration of the AACS and CDS. All other subsystems have performed as required.

The first phase of spacecraft integration—electrical and functional compatibility between the orbiter and probe systems—occurred in September 1983. Major tasks included integration of 1) the relay radio hardware into the orbiter, 2) the probe and the orbiter, and 3) the mission telemetry system (MTS) and the probe flight operation equipment (PFOE), as well as a probe end-to-end data test.

Updated orbiter and probe hardware is scheduled to be delivered to JPL's Spacecraft Assembly Facility (SAF) starting January 16, 1984. Spacecraft integration will resume in February 1984 when the orbiter and probe are electrically connected. The first phase of system test will take place this spring, followed by environmental tests this summer, and the second phase of system tests in the fall.

The spacecraft is scheduled to be capable of being committed to flight by March 1, 1985.

Bill Layman is the Galileo project engineer, Frank Tillman is the environmental test director, and Jim Staats is the static test director, all of the Applied Mechanics Division.
Exploded view of Galileo spacecraft and upper stage.