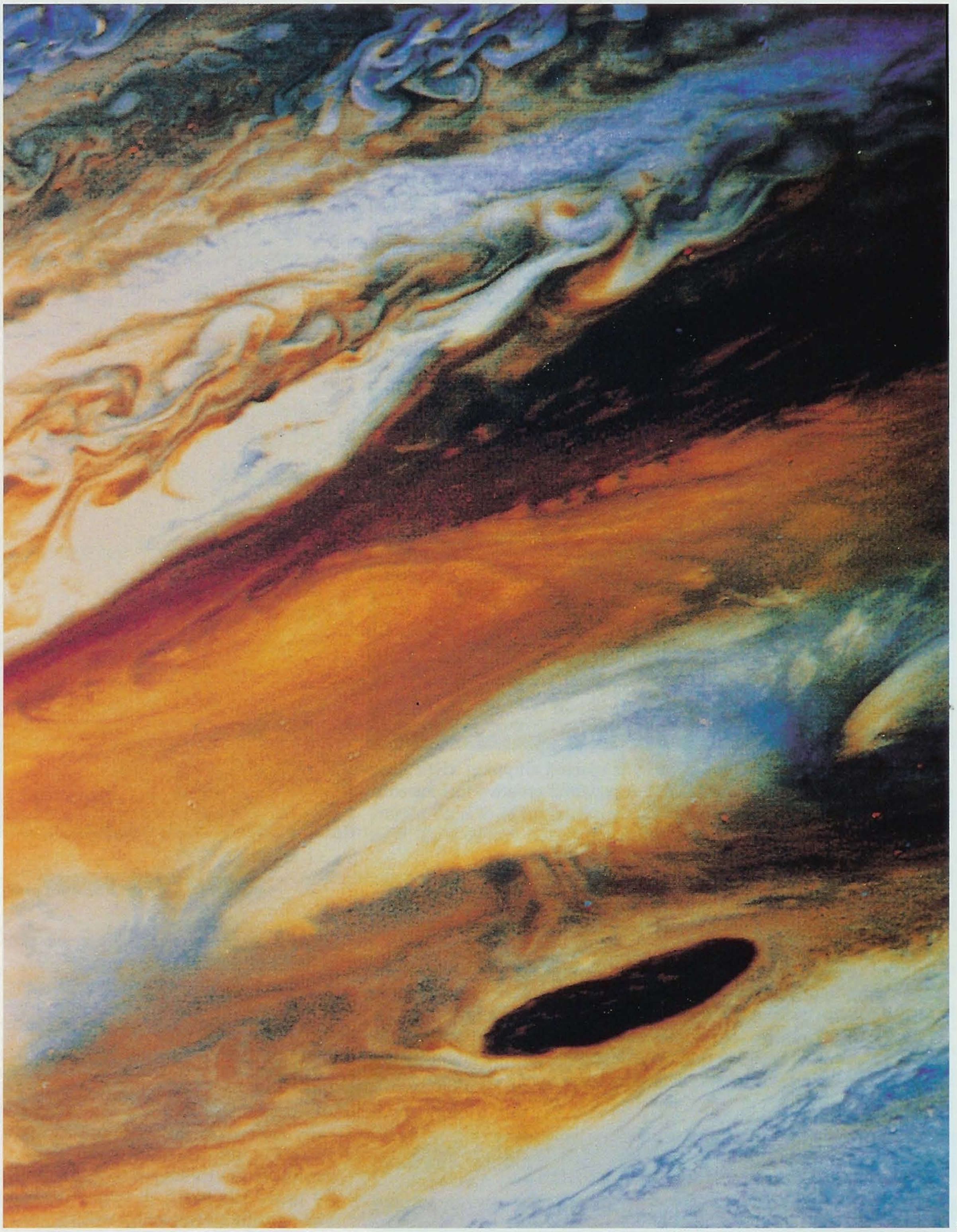
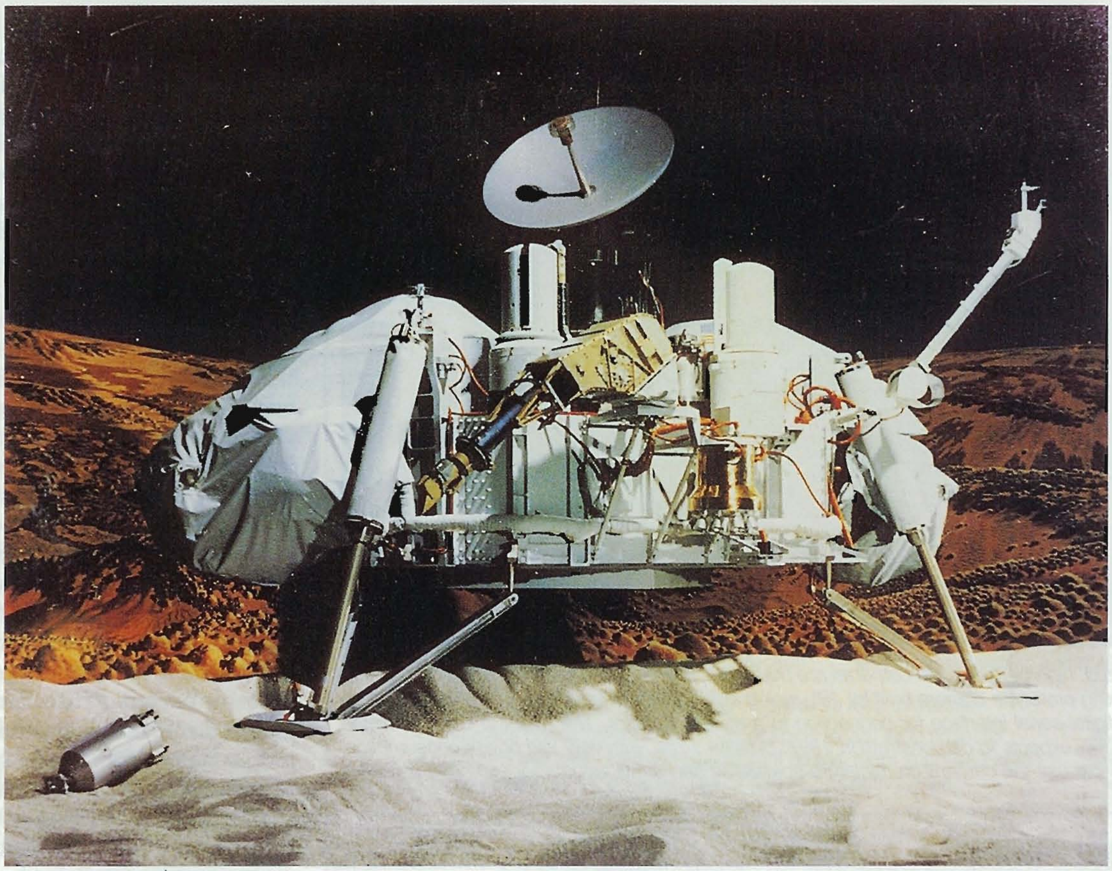
DIGITAL DIRECTIONS



Color composite of Jovian atmosphere.

The Jet Propulsion Lab in Pasadena: *Imaging on the Cutting Edge*



Viking Lander

WHILE IT ALL seems so simple now, it was revolutionary at the time to try to turn photographs into streams of digital data—to take visual elements and turn them into numeric values.

A CMOS CAMERA will be onboard an upcoming military satellite. For photography, it could well mean the next revolutionary image-capture technology.

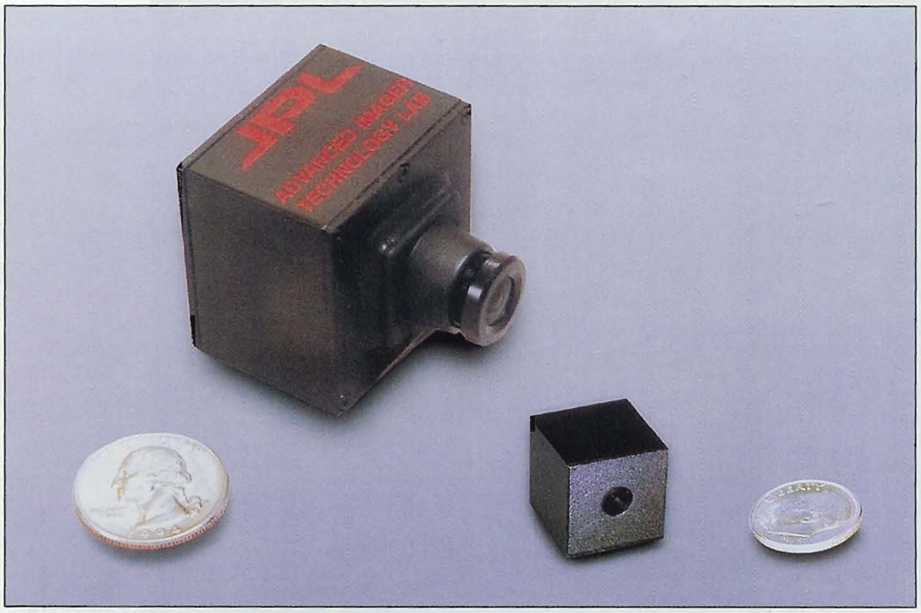
Ron Eggers

Editor's note: This is the first of two articles about NASA's Jet Propulsion Laboratory, and how developments in deep space imaging continue to have a significant impact on commercial photography. An overview of the facility's traditional photo lab, run by David Deats, will appear in our September issue.

THE GALILEO SPACECRAFT silently cut through the void of deep space at thousands of miles per hour—Earth quickly fading into a pale blue dot as the craft made its way toward Jupiter. Galileo was on a mission—a deep space mission to study the giant planet and determine what the atmosphere, and the planet itself are actually made of.

By the time Galileo reached Jupiter, it had already transmitted some striking images of planetary and asteroid encounters, and its imaging systems kept shooting during the fly-by. The images and the scientific data that continue to be sent back by Galileo are captured by National Aeronautics and Space Administration's (NASA) Deep Space Network ground stations in California, Spain and Australia, where they are retransmitted to the Jet Propulsion Laboratory (JPL) in Pasadena, CA.

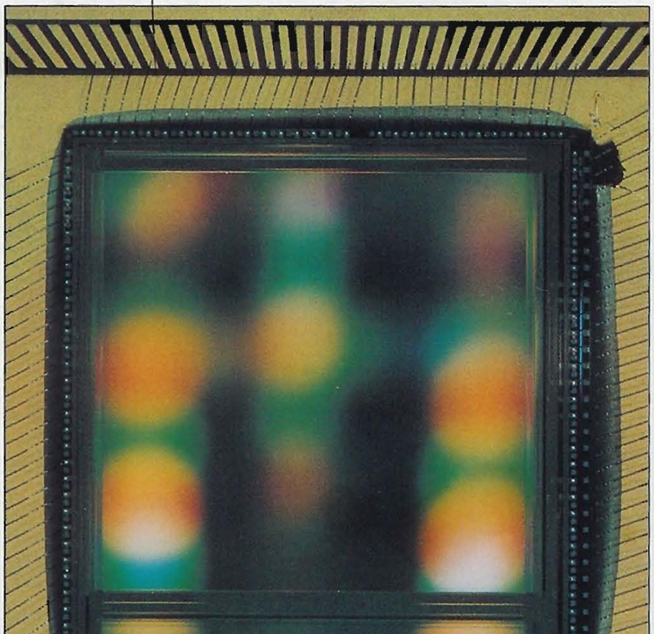
Run by nearby California Institute of Technology under contract to NASA, JPL is responsible for developing, managing and communicating with unmanned deep space missions and some



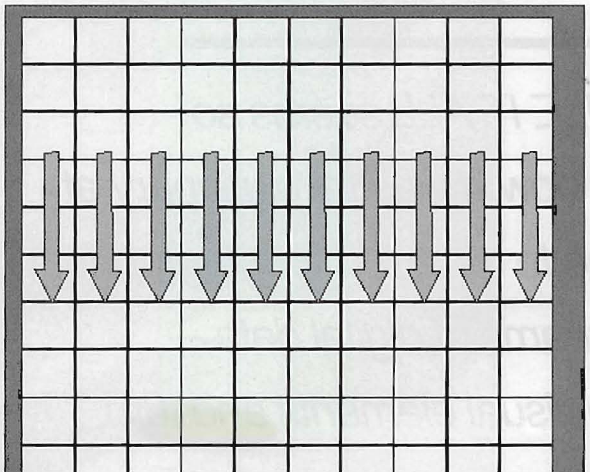
Highly miniaturized, high performance cameras are made possible by the CMOS APS technology. On the left is a working prototype camera built by JPL, using a 256x256 lower resolution CMOS chip. The camera has a digital serial interface for connection to a microprocessor. The mockup camera on the right is the size JPL expects to demonstrate in 1997. Smaller sizes, with very low power consumption, will enable NASA to use the camera on miniature spacecraft and small landers for exploring asteroids and comets.

Earth-orbiting satellites. In the process, the research facility has developed the field of deep space imaging, and parallel commercial imaging innovations. JPL is the facility that generated the beautiful shots of the rings of Saturn, the surface of Mars, the distant asteroids, and many other never-before-seen close-ups, from the raw digital data that various space missions have transmitted back.

For scientists trying to figure out the wonders of the universe, a picture is worth more than a thousand words, and images from explorations like the Mariner, Voyager and Viking missions have made headlines and fascinated viewers around the world. Since the first U.S. satellite, Explorer I, in 1958 (which was built at JPL for the U.S. Army), the facility's spacecraft have orbited or flown by the sun and every planet in the solar system, except Pluto. But, for those involved in commercial imaging, JPL's image pioneering also lays down the framework for tomorrow's marketplace.



A 1024 x 1024 element complementary metal-oxide-semiconductor (CMOS) active pixel sensor (APS) array with digital output. The chip size is approx. 14mm x 15mm and contains more than 5 million transistors. The chip was designed by R. Panicacci and B. Mansoorian of the Jet Propulsion Laboratory.



To understand the significance of the new CMOS technology, it helps to understand how current digital photography works. Most digital imaging is being done by charge-coupled device (CCD) sensors, which actually capture an analog image (electrons) and then convert it to digital.

The sensor operates by collecting the light-generated signal in electronic "buckets," and then shifts those signals to a single output in the corner of the chip. Most CCDs contain approx. 300,000 pixels.

The quality of CCD sensors has improved significantly during the last few years, but, since their production requires a highly specialized chip formula, they are expensive; and, since they are on such a specialized chip, they can't be easily integrated into the other circuitry required for CCD capture devices.

Once those electrons have been captured by the CCD, there has to be a way to move them to a place where they can be amplified and either digitized or transferred to an analog device such as a VCR. Since the electrons are still in an analog form, shifting them from position to position across the CCD can degrade the image.

The Advent of Digital Technology

More than 35 years ago JPL was faced with the challenge of getting images from spacecraft back to Earth. The problem wasn't in the reception from spacecraft to ground stations. Radio waves travel effectively in outer space, and the technology was far enough along for reliable communication links to be established. The problem was how to get the photographs that were recorded by the spacecraft into a form that could be transmitted very long distances over radio waves.

Scientists came up with a plan: Rather than having one continuous-tone image taken by the onboard camera, design the camera with individual sensors. In other words, break each image up into a grid, of sorts, with each position on that grid having an independent light sensor, or element. The image would be taken through a lens, just as with conventional photography, but instead of falling on film, it would fall on the 800 x 800 position grid (a picture element, or pixel array).

The individual light sensors measured the amount of light (the photons) that fell on that position and turned that energy into electrons which could be measured, resulting in a numeric value of each position on the sensor grid. That worked well for black and white shots and, by shooting through filters, could also be used for generating color images. The numeric values were then strung together and transmitted back to Earth. The ground stations retransmitted the data to JPL, where the individual light values were reassembled by position. In effect, the entire image was recreated from the digital data.

While it all seems so simple now, it was revolutionary at the time to try to turn photographs into streams of digital data—to take visual elements and turn them into numeric values. Those early images weren't high quality, but they did provide the visual information scientists were looking for. They could show details about planets, asteroids or moons that couldn't be gathered by any other means: Digital imaging worked.

Today's Imaging for Tomorrow

JPL's Science Data Analyses Section (imaging center), is set up to handle myriad incoming images, with more than 150 Silicon Graphics, Sun Sparc, Pentium and Mac workstations installed. "All of them are totally networked," says Dr. Raymond J. Bambery, who, as supervisor of the Image Processing Laboratory, heads the Multi-mission Image Processing (MIPS) Engineering and Operations group within the Analyses section.

"There are multiple networks that are fully redundant," says Bambery. "Redundancy" is important, since this is where most of the data coming from the various spacecraft are initially processed. "We're the in-node for the entire (high-rate) telemetry system for JPL," he says. "Ninety percent of the data being processed is either imaging or in the imaging spectrometer."

Galileo may not be sending the volume of images that was originally planned for (due to much-publicized problems with the high-gain antenna), but images from it and several previous missions *are* coming in, and these images take up a tremendous amount of disk storage space. Even with more than 500 gigabytes of storage, capacity is still tight. There are plans to increase storage to a full terabyte (1,000 gigabytes) by next year, and currently, images are rolled off to CD-ROMs for long-term storage.

Most of the images on the 120,000 computer tapes the department has accumulated have also been written to CD. "All the archives, from 1964, when Mariner 1 launched, are being put on CDs," Bambery says. (There's still one old DEC VAX with tape readers installed, so that tapes that haven't yet been transferred can be accessed. "It runs all the old software," Bambery says, "so we'll keep that for a number of years.") A 500-slot CD-ROM jukebox simplifies access to currently required CDs.

Bambery's department is also involved in video imaging. JPL is noted for its sophisticated fly-bys, and fly-overs of the Martian landscape, Jupiter's moons, and Earth's terrain. Work is in progress on high-definition TV to increase the quality of the videos that are being generated.

Almost all of the actual photo output is handled by JPL's extensive Photo Department (to be covered next month in detail). The Imaging Department, however, handles large format transparency output on its Cymbolic Sciences film recorders. The exposed film is then taken to the Photo Department for processing.

Banbery's group is charged with the design and building of systems to meet specific computing needs within JPL. At one point, almost everything was proprietary equipment specifically designed for JPL. Interestingly enough, that has changed. "Now, we primarily assemble off-the-shelf equipment. It's much more cost effective that way," Bambery says.

Reality

The national space program has a proud and distinguished history, but it is going through hard times now. With the national debt in the trillions of dollars, annual budget deficits still in the hundreds of billions of dollars, and federal entitlements growing much faster than the population or the economy, expenditures for seemingly optional programs like space exploration have been cut drastically.

Space projects that at one point had virtually open-ended budgets are now on tight reins, with fixed-expenditure contracts, and the proposed Space Station has been redesigned several times in an effort to cut costs. JPL's billion-dollar-plus annual budget hasn't been hit too hard—at least not yet: It only shrank about 5 percent from 1994 to 1995, but more cuts are imminent. The new emphasis on economy in the federal budget is forcing NASA and JPL to come up with innovative ways of carrying out their missions.

Imaging: The Future

Currently, the most promising approach for long-term savings is miniaturization. JPL's wide-scale efforts in microspacecraft technology are designed to lead to major decreases in sub-system sizes and weights, while at the same time significantly reducing power consumption. It is this direction that has led to recent advances in imaging, as well as such things as miniature guidance gyros, and complete spacecraft command and data-handling sub-systems weighing less than 5 lbs.

Engineers looking further ahead in technology are talking about a "spacecraft on a chip"—a complete set of systems reduced to integrated circuits and micro-devices mounted on a single substrate.

One of the promising micro-technologies currently in development is a new digital camera. "The CMOS APS camera will change space imaging. It will also change digital photography," Dr. Eric R. Fossum, a senior research scientist and assistant section manager for Technology and Spectrometry Systems, and one of the inventors of the camera, says.

The new CMOS APS (complementary metal-oxide-semiconductor active pixel array) camera is an entirely new technology. It's basically a complete digital camera on a chip. The amplifiers, transistors and all the circuitry required to make it work are contained within each pixel.

Like CCDs, the new CMOS camera works with a grid, but it's a different type. Each position on that grid is like a micro CCD. There are many thousands of these micro CCDs on the chip, according to Fossum. The CCDs are addressed through the x-y grid scheme. There's no shift registry required. With no electron shifts involved, no specialized silicone material is required, either.

Because the CMOS chips are made of the same silicon material microprocessors and memory are made of, virtually all the required circuitry can be designed into the chip—no added circuitry is required. The timing and control circuits, the analog signal processing, the analog to digital conversion and the sensor controls can all be on the same chip. Commercially, in mass production, it will cost about 20 percent as much to build a CMOS chip as it does to build the same functionality into a CCD chip set.

There are still some limitations to CMOS technology. For now, the pixel arrays can't be quite as large with CMOS as they can be with CCDs, and the pixel size itself can't be made as small with the CMOS as with CCDs. "That should change within two years, though," Fossum says.

The first CMOS chip, which had the very low resolution of 28x28 for a pixel array of 784, was produced in April 1993. The most recent lab prototype has a 1024 x 1024 grid for a 1-million pixel array. Fossum has prototype models smaller than a cigarette lighter, with sizes just a little larger than a sugar cube in development. The small size is obviously a major innovation, but just as important is the reduced power consumption of the new camera. It takes as little as 1 percent of the power CCDs require to generate images of similar quality.

The new camera has tremendous potential in a wide range of imaging applications. Obviously, the CMOS camera will enhance space imaging, not only for future microspacecraft but also on conventional missions. No longer would all the mechanics used to rotate, pan and re-position an on-board camera be needed for different views to be photographed. Numerous cameras could be placed on board that, together, cover the entire field of view. And that's only the start. Cameras could be placed in positions where they just wouldn't have been practical to do so previously, enhancing the amount of visual data being generated by a mission.

A CMOS camera will be onboard an upcoming military satellite, to see how it functions in space. The first scientific application of the technology is scheduled to be on the Millennium project, which will have both CCD and CMOS technology onboard for comparison.

For photography, it could well mean the next revolutionary image-capture technology. On the consumer level, CMOS could open up digital photography much the same way that instamatic cameras opened up conventional photography to the masses. Further down the road, Fossum sees CMOS chips being used in disposable digital cameras. At the high end, it could make digital imaging equipment competitive with conventional photographic gear. Fossum estimates that, within three years, low-end digital cameras will cost around $100, while high end versions will cost around $1,000.

"It's projected to be a huge market. It's staggering," Fossum says.

JPL has been working with private industry to transfer the technology Fossum is developing. "We've been working with AT&T, Kodak, National Semiconductor and several other companies to transition the technology into the commercial sector," Fossum says. His wife, Dr. Sabrina Kemeny, a former JPL researcher who is also one of the inventors of the camera, in 1995 set up a new company, Photobit, that handles custom CMOS image sensor design for corporate customers. The company's mission is to develop and apply this technology both internally and through corporate alliances, and Photobit will soon offer electronic imaging products targeting commercial markets. A key application will be high resolution digital photography.

At this point, most companies involved don't want to talk about what their plans for CMOS technology are until they're ready to announce specific products. Widespread commercial applications may still be a couple of years away. Some companies in the photo industry are looking at competing technologies before committing to the CMOS camera.

With CMOS integration into the space imaging program, it's highly likely that it will win out in the end. If it does, it will not only change imaging, it will also close a technology gap that currently exists between the United States and Japan. Japan makes the vast majority of the world's CCDs. The new CMOS technology could bring design and production back to the States. "All of a sudden, U.S. business can be competitive in imaging again," Fossum points out. Supposedly, Japanese corporations are worried because they're locked out. "This technology was funded by U.S. taxpayers. It's a political issue. No license has been issued outside of the U.S.," Fossum says.

Taxpayers should understand that JPL is involved in much more than just space flight. It is on the cutting edge of technology, which often translates into megadollars in the commercial/industrial marketplace. Its research projects extend from the lowest levels of the oceans to the peaks of major mountain ranges and far beyond, and advances in a wide range of disciplines can be traced to its front door.

Editor's note: For more Photobit/CMOS technology information, contact: Photobit, 2529 Foothill Blvd., Suite 104, La Cresenta, CA 91214; (818) 248-4393, fax (818) 542-3559.

(Next Month: The significant role of JPL's Photo/Imaging Department, under the direction of David Deats.)

Ron Eggers is a senior editor with Photo Lab Management *and a senior editor with* NewsWatch Feature Service. *He can be reached by e-mail at 71210.3556@compuserve.com.*