tive-triple-point areas where the sensing electrode, electrolyte, and sample gas meet. These areas are formed by cutting openings in the electrolyte membrane. The electrode current generated from electrochemical oxidation of ethylene at the active triple points is proportional to the concentration of ethylene. An additional film of the solid-electrolyte membrane material is deposited on the sensing electrode to increase the effective triple-point areas and thereby enhance the detection signal.

The sensor chip is placed in a holder that is part of a polycarbonate housing. When fully assembled, the housing holds the solid-electrolyte membrane in contact with the chip (see figure). The housing includes a water reservoir for keeping the solid-electrolyte membrane hydrated. The housing also includes flow channels for circulating a sample stream of air over the chip: ethylene is brought to the sensing surface predom-

inately by convection in this sample stream. The sample stream is generated by a built-in sampling pump. The forced circulation of sample air contributes to the attainment of a low detection limit.

In addition to the sensor and the sampling pump, the apparatus includes electronic circuitry for regulating the sensor potentials, measuring the sensing-electrode current, and displaying the ethylene-concentration reading. The electronic circuitry includes a data logger for digital collection via a serial port with an optional analog output.

Overall, the apparatus is capable of measuring ethylene concentrations from 5 to 5,000 ppb with a response time of less than 30 seconds. The magnitude of response of the sensor current is in the range of 5 to 50 picoamperes/ppb. The signal-to-noise ratio is greater than 3 at the low detection limit of 5 ppb.

The sensor is fairly selective for ethylene. It is not subject to interference by O_2 or CO_2. It does respond to NO, NO_2, and H_2S, but these gases are generally not expected to be present at significant concentrations in controlled plant-growth environments. The sensor also responds to some volatile compounds present in some soil samples. Further research will be necessary to reduce these interferences.

# Increasing Linear Dynamic Range of a CMOS Image Sensor
Dual-gain pixels are automatically switched to the most appropriate gain level.

NASA's Jet Propulsion Laboratory, Pasadena, California

A generic design and a corresponding operating sequence have been developed for increasing the linear-response dynamic range of a complementary metal oxide/semiconductor (CMOS) image sensor. The design provides for linear calibrated dual-gain pixels that operate at high gain at a low signal level and at low gain at a signal level above a preset threshold. Unlike most prior designs for increasing dynamic range of an image sensor, this design does not entail any increase in noise (including fixed-pattern noise), decrease in responsivity or linearity, or degradation of photometric calibration.

The figure is a simplified schematic diagram showing the circuit of one pixel and pertinent parts of its column readout circuitry. The conventional part of the pixel circuit includes a photodiode having a small capacitance, C_D. The unconventional part includes an additional larger capacitance, C_L, that can be connected to the photodiode via a transfer gate controlled in part by a latch.

In the high-gain mode, the signal labeled TSR in the figure is held low through the latch, which also helps to adapt the gain on a pixel-by-pixel basis.
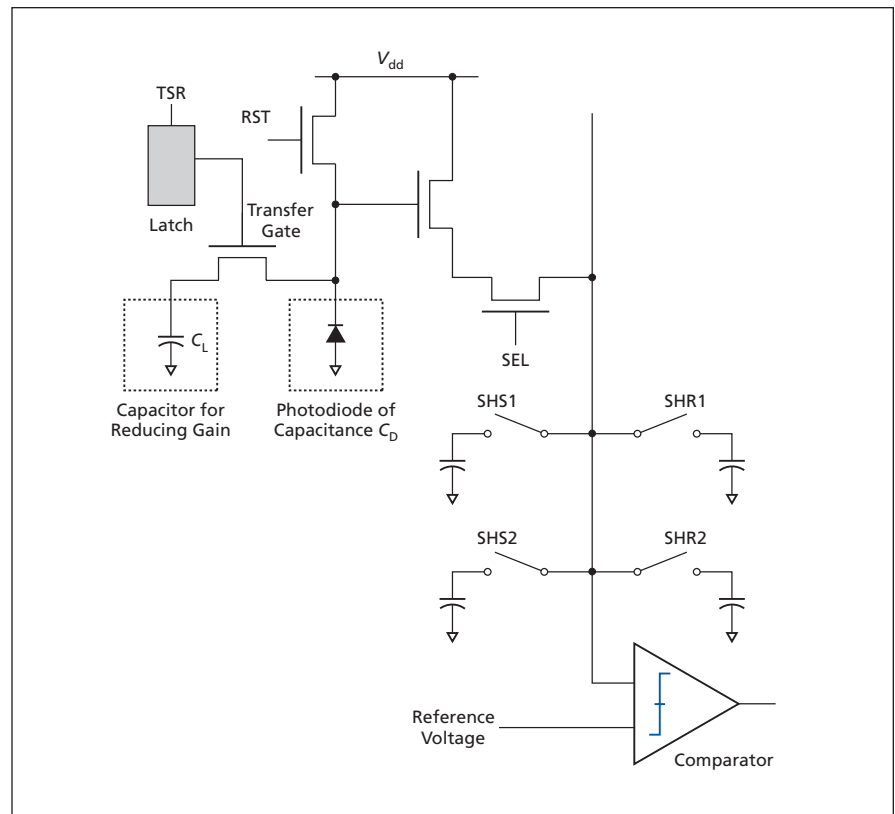
The **Pixel and Column Readout Circuitry** enable operation in either of two gain modes and automatic choice of whichever mode is appropriate for the present illumination level.

Light must be coupled to the pixel through a microlens or by back illumination in order to obtain a high effective fill factor; this is necessary to ensure high quantum efficiency, a loss of which would minimize the efficacy of the dynamic-range-enhancement scheme. Once the level of illumination of the pixel exceeds the threshold, TSR is turned on, causing the transfer gate to conduct, thereby adding C_L to the pixel capacitance. The added capacitance reduces the conversion gain, and increases the pixel electron-handling capacity, thereby providing an extension of the dynamic range.

By use of an array of comparators also at the bottom of the column, photocharge voltages on sampling capacitors in each column are compared with a reference voltage to determine whether it is necessary to switch from the high-gain to the low-gain mode. Depending upon the built-in offset in each pixel and in each comparator, the point at which the gain change occurs will be different, adding gain-dependent fixed pattern noise in each pixel. The offset, and hence the fixed pattern noise, is eliminated by sampling the pixel readout charge four times by use of four capacitors (instead of two such capacitors as in conventional design) connected to the bottom of the column via electronic switches SHS1, SHR1, SHS2, and SHR2, respectively, corresponding to high and low values of the signals TSR and RST. The samples are combined in an appropriate fashion to cancel offset-induced errors, and provide spurious-free imaging with extended dynamic range.

Flight Qualified Micro Sun Sensor

Attributes include compactness, low mass, and low power consumption.

NASA's Jet Propulsion Laboratory, Pasadena, California

A prototype small, lightweight micro Sun sensor (MSS) has been flight qualified as part of the attitude-determination system of a spacecraft or for Mars surface operations. The MSS has previously been reported at a very early stage of development in *NASA Tech Briefs*, Vol. 28, No. 1 (January 2004).

An MSS is essentially a miniature multiple-pinhole electronic camera combined with digital processing electronics that functions analogously to a sundial. A micromachined mask containing a number of microscopic pinholes is mounted in front of an active-pixel sensor (APS). Electronic circuits for controlling the operation of the APS, readout from the pixel photodetectors, and analog-to-digital conversion are all integrated onto the same chip along with the APS. The digital processing includes computation of the centroids of the pinhole Sun images on the APS. The spacecraft computer has the task of converting the Sun centroids into Sun angles utilizing a calibration polynomial.

The micromachined mask comprises a 500-µm-thick silicon wafer, onto which is deposited a 57-nm-thick chromium adhesion-promotion layer followed by a 200-nm-thick gold light-absorption layer. The pinholes, 50 µm in diameter, are formed in the gold layer by photolithography. The chromium layer is thin enough to be penetrable by an amount of Sunlight adequate to form measurable pinhole images. A spacer frame between the mask and the APS maintains a gap of ≈1 mm between the pinhole plane and the photodetector plane of the APS.

To minimize data volume, mass, and power consumption, the digital processing of the APS readouts takes place in a single field-programmable gate array (FPGA). The particular FPGA is a radiation-tolerant unit that contains ≈32,000 gates. No external memory is used so the FPGA calculates the centroids in real time as pixels are read off the APS with minimal internal memory. To enable the MSS to fit into a small package, the APS, the FPGA, and other components are mounted on a single two-sided board following chip-on-board design practices (see figure).
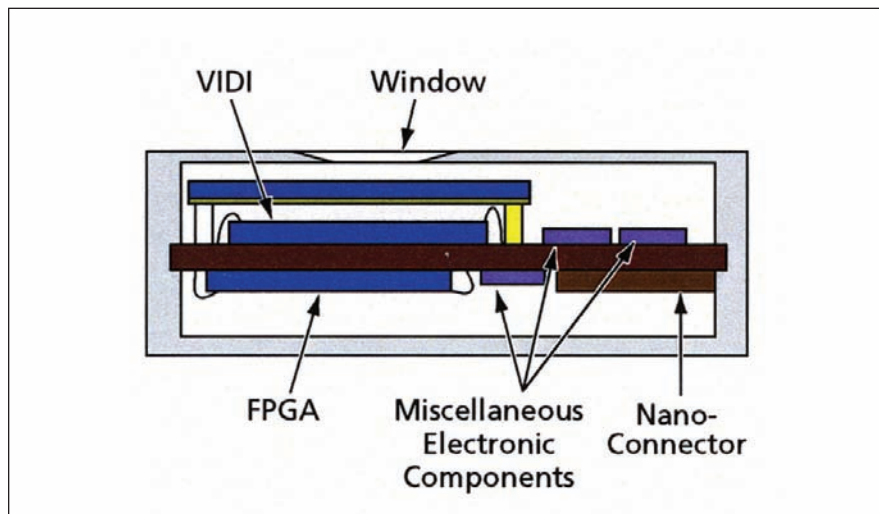
The **Entire MSS** fits into a compact package.