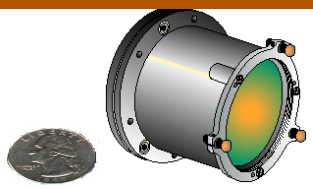




# Micro Digital Solar Attitude Detector and Imager

**Stephen E. Jaskulek**
**The Johns Hopkins University**
**Applied Physics Laboratory**
**Mail Stop 4-240**
**11100 Johns Hopkins Road**
**Laurel, MD 20723-6099**
**(tel) 240-228-5087**
**(fax) 240-228-7636**
**email: stephen.jaskulek@jhuapl.edu**

**Kim Strohbehn**
**The Johns Hopkins University**
**Applied Physics Laboratory**
**Mail Stop 4-202**
**11100 Johns Hopkins Road**
**Laurel, MD 20723-6099**
**(tel) 240-228-8293**
**(fax) 240-228-7636**
**email: kim.strohbehn@jhuapl.edu**

**Mark N. Martin**
**The Johns Hopkins University**
**Applied Physics Laboratory**
**Mail Stop 23-256**
**11100 Johns Hopkins Road**
**Laurel, MD 20723-6099**
**(tel) 240-228-7895**
**(fax) 240-228-1093**
**email: mark.martin@jhuapl.edu**

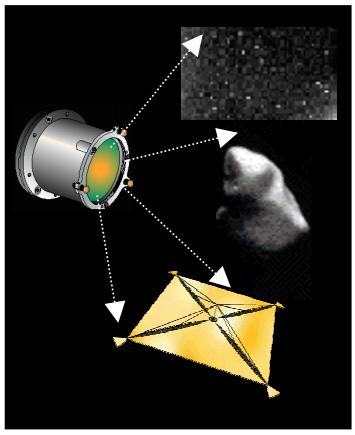
Abstract

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has developed the first generation of a micro digital solar attitude detector (DSAD). The micro-DSAD (µDSAD) design is based on our patented approach of combining a centroiding position-sensitive active-pixel architecture with standard imaging capability for providing optional "engineering channel" images. This approach avoids the need for a DSP (digital signal processor) in computing the position, thus dramatically lowering the required mass and power resources. The µDSAD technology is presently at Technology Readiness Level (TRL) 5. We have demonstrated robust performance, significant total dose radiation tolerance, and single-event latchup immunity on small format prototype devices.

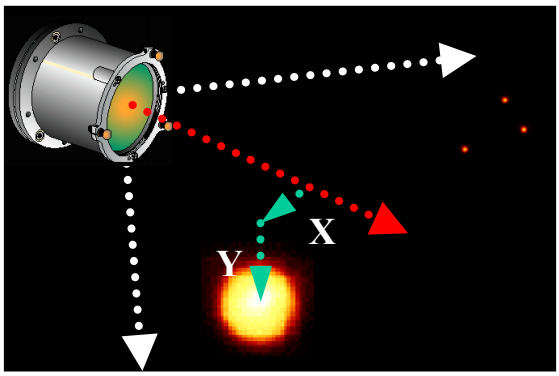
The proposed µDSAD realizes a significant breakthrough in meeting the requirements for the Sun sensor needed as part of ultra-low-power electronics and avionics. The µDSAD device can also be used as an medium resolution imager for use in monitoring solar panel, boom, and antenna deployments or for sighting stars or other items of interest. Incorporating the entire sensor and its interface on a single chip enables us to create a sensor small enough to be of great utility in microsatellites for spacecraft formation flying, as well as applicability in nearly all NASA spacecraft missions.

Many proposed missions depend on the use of "microsatellite" constellations to make simultaneous measurements at different orbital locations. Numerous new technologies are required to make the microsatellite concept viable from a mass and power standpoint. The apparent position of the Sun is an important spacecraft attitude measurement that is used by virtually all attitude determination and control subsystems. This measurement is commonly made with a sensor called a digital solar attitude detector (DSAD). A micro-DSAD (µDSAD) incorporating the entire sensor and its interface on a single chip would enable one to create a sensor small enough to be of great utility in microsatellites for spacecraft formation flying, as well as applicability in nearly all NASA spacecraft missions.

As part of the highly integrated electronics thrust area of the NASA Advanced Technology Development program, The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has developed the first generation of such a µDSAD integrated circuit for use in microsatellites. The µDSAD design is based on our patented approach of combining a centroiding position-sensitive active-pixel architecture with standard imaging capability for providing optional "engineering channel" images. This approach avoids the need for a DSP (digital signal processor) in computing the position, thus dramatically lowering the required mass and power resources. The µDSAD technology is presently at Technology Readiness Level (TRL) 5. We have demonstrated robust performance, significant total dose radiation tolerance, and single-event latchup immunity on small format prototype devices.



The proposed µDSAD realizes a significant breakthrough in meeting the requirements for the Sun sensor needed as part of ultra-low-power electronics and avionics. The µDSAD device can also be used as an medium resolution imager for use in monitoring solar panel, boom, and antenna deployments or for sighting stars or other items of interest. Thus, one can view the µDSAD as a multi-faceted breakthrough that meets several needs at once.




One of the most difficult aspects of developing new spacecraft technology is the transition beyond the mid-TRL levels to flight-ready hardware that can be readily purchased or obtained. We are addressing this problem by via an earlier demonstration flight and commercialization efforts.

We have negotiated an arrangement to fly two prototype µDSAD cameras on the NASA Comet Nucleus Tour (CONTOUR) mission, which is scheduled for launch in late 2002. This provides us the opportunity to verify the operational characteristics of the optics, detector, and electronics under actual flight conditions.

In parallel with this effort, we are transitioning the technology to a commercial partner for incorporation into a commercial product available to the whole space community. JHU/APL has recently licensed the µDSAD technology to Goodrich Aerospace. Their Optical and Space Systems Group has an

extensive history in providing high quality, space-qualified attitude sensors.

### Technology Description

A digital solar altitude detector (DSAD) is a sensor assembly that computes the two dimensional position of a bright spot within its field of view (FOV). All DSAD detectors are comprised of an optical system, (often a pinhole, or an array of slits), a position-sensitive detector (sometimes constructed from an array of discrete photo-detectors), and an electronic signal processing system to provide an interface to the spacecraft. DSAD sensors are required to have a large field of view so that the Sun is always detected with a minimum number of sensor assemblies. As a result, the low magnification optics can be very short. Also, because the Sun is very bright, a small aperture suffices to collect enough photons for detection in a reasonable integration time. Since the DSAD optical system can be very compact, for example a pinhole lens, we have focused our efforts to date on integrating the position-sensitive detector and processing electronics onto a single radiation tolerant, integrated circuit. The single-chip position-sensitive detector and electronics unit results in a μDSAD sensor with minimal size (set by the optics), power, and cost.

It is very desirable to integrate the position-sensitive detector on the same chip as the support electronics. This is difficult and costly with a charge-coupled device (CCD) detector, so a detector compatible with complementary metaloxide semiconductor (CMOS) processing is favorable. An additional disadvantage of most CCD detectors is the need for high-voltage, high-transient current peripheral clocking circuitry. The μDSAD must be sufficiently radiation tolerant to be used in almost any commercial space or NASA mission. A total dose tolerance of a few hundred kilorads is very desirable; in addition, the detector must be immune to single event induced latch-up (SEL), and the effects of single event upsets (SEU) must be mitigated. The requirement for total dose radiation tolerance also favors CMOS based detectors over CCDs. Conventional CCD arrays are typically tolerant only to tens of kilorads, and active-pixels based on photo-gates suffer much higher dark current, both pre-rad and post-rad, than photodiode pixels [1].

Modern CMOS processes feature very thin gate oxides, so that threshold shift in the drawn transistors is tolerable to quite high doses. However, leakage through parasitic n-channel field devices limits the total dose tolerance of commercial processes in many cases to approximately 20 krad. We have developed a layout style based on annular n-channel transistors [2,3] that essentially eliminates this leakage path at the cost of area, thereby achieving total dose tolerance in excess of 300 krad with commercial processes. By using special layout rules, we also minimize the risk of SEL. SEU mitigation relies primarily on system-level techniques. Our layout style enables us to utilize commercial CMOS foundries, and avoid the costly use of dedicated radiation-hardened processes. With the freedom to choose a commercial process, we have selected the AMI Corp. C5N process for our designs. This 0.5 μm process is attractive because AMI is committed to maintaining it (longevity), and it is available for low cost prototyping through the MOS Implementation System (MOSIS) service. In addition the C5N process features double poly and triple metal among its virtues.

Most imaging arrays, such as active-pixel sensors, must be read out, and the image analyzed by digital signal processing (DSP) techniques (often requiring a microprocessor subsystem) to compute the solar spot position. This is a disadvantage over the lateral-effect detector approach, because it increases system complexity and power dissipation, while decreasing the throughput. Integrated systems with the DSP electronics on-chip potentially suffer from substrate noise coupling, as well as the need for more elaborate SEU mitigation.

As part of the NASA-JHU/APL ATD Program, we have developed a novel active-

pixel design that avoids the above disadvantages. Our patented design approach [4] starts with the position-sensing pixel proposed by DeWeerth and Mead [5], and adds the ability to read out the pixel brightness value [6]. An active-pixel array based on this pixel design boasts all the advantages of an active-pixel imager, but includes analog position sensitivity, such that a center of brightness spot position can be computed without reading out the array, or performing any digital signal processing. The sensor directly outputs a two axis position of the Sun in the FOV.

Figure 1 is a schematic of our pixel design. The photodiode is implemented as a floating n-well/p-substrate diode. This diode is attractive because it has lower capacitance, and a deeper junction than a source-diffusion/p-substrate diode. To obtain a radiation-tolerant design, any n-channel devices need to be drawn using annular design style. Therefore, we chose to use all p-channel active devices to minimize pixel area, while taking into account the need for a separate well with enough spacing to isolate the floating n-well diode. The pixel is 21 μm square, and the n-well diode is 4.8 μm square. These dimensions result in a fill factor of about 5%, neglecting carrier diffusion in the substrate.

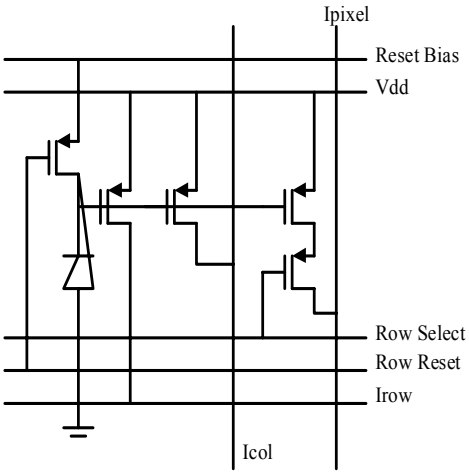



**Figure 1.** Position-sensitive active-pixel schematic.

The detector capacitance is dominated by the three transistor gates at the cathode (maximum value of 38 fF).

The operation of the pixel is as follows. The photo-cathode is reset to the Rbias level, and then released. The photo-charge then integrates on the photo-cathode and the three signal gates. One signal device is used to contribute current to a column line, and a second device contributes current to a row line. These signals are used at the periphery of the array to construct a position estimate. The third signal device can be selected to drive a pixel current line that can be used to read out an image if desired.

Figure 2 is a simplified diagram of the active-pixel array based on this pixel design. The array of pixels is used to determine the center of brightness of the incident illumination. The array can also be scanned out to produce a slow scan image for housekeeping functions. Most

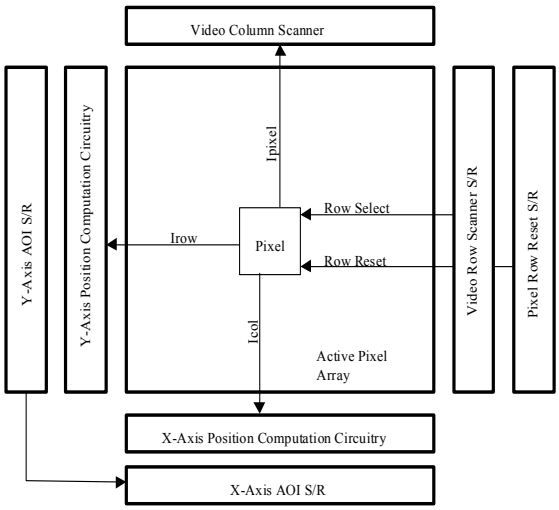



**Figure 2**. Position-sensitive

of the building blocks shown in Figure 2 are relatively straightforward; we employed only annular n-channel transistors throughout the design to minimize leakage due to total dose. Unbroken guard rings are used to minimize the likelihood of single-event latchup (SEL).

Operation of the x- and y- channel position computation circuits is indicated in Figure 3. The position circuits are identical for both x (column currents) and y (row currents), so we

need only consider the column current case. As shown in Figure 3, each column-current line from the active-pixel array provides the tail current for a simple one-stage transconductance amplifier. The position along the array is coded by a resistive divider, so that the non-inverting input of the transconductance amplifier at column x is tied to a tap on the position-coding voltage divider at voltage Vr(x). The amplifiers are configured as unity gain followers with their outputs shorted together on the V position line.

The row and column select lines are configurable in the digital logic such that we can define areas of interest on the array; only those rows and columns that have been enabled in the configuration registers contribute to the centroiding calculation.

This windowing function is a very powerful tool because it allows the ability to deal with earth albedo and spacecraft structures which may be in the field of view. It also can eliminate glint or bad pixels from disturbing the light centroiding calculation.

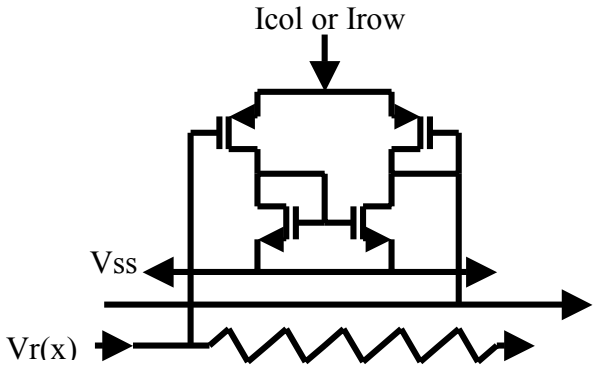



Figure 3. Position computation circuit.

The µDSAD is configured and operated over the I2C "2-wire" interface. In either DSAD or image mode, the Area of Interest (AOI) coordinates are placed in four registers to configure the device. The AOI determines which pixels will participate in the position computation in DSAD mode, and which pixels will be read out in image mode. A subsequent position read will return the digitized X and Y solar coordinates to the S/C. An "expose image" command will expose the array for the amount of time stored in the exposure register, and then MUX out, digitize, and transfer the AOI image data to a small buffer in the µDSAD assembly. The image can be read from the buffer be a read image request via I2C.

The ASIC may be used in its imaging mode by reading out the brightness sensed by each pixel. Typically a single row is selected, and then each column is sequentially read out. Time aliasing effects may be removed by reading out the array after the pixels have been reset and subtracting this baseline from the imaged values. Because of the inter-pixel isolation, there is little "bleed-through" between bright and dim pixels.

### Progress to Date

Several versions of the DSAD ASIC have been fabricated to date. The DSAD2A and DSAD2B chips, seen in Figure 4a, were designed as proof of concept devices, and contain an array of 64x64 pixels. Most support circuitry was left off-chip, and they have no internal ADC.

The full-featured DSAD3 chip, seen in Figure 4b, requires only an external field-programmable gate array (FPGA) and a bypass capacitor to function as a DSAD sensor. It provides an I2C interface (four wires including power and ground), and it dissipates less than 20 mW. The 200 × 200 µDSAD includes several analog support circuits including a 10-bit, successive-approximation analog to digital converter (ADC), an analog MUX (multiplexer), bias generation circuitry, a readout amplifier, a clock generator for the digital support circuitry, and a voltage reference. An SRAM (Static Random Access Memory) chip may also be used to facilitate simple readout for the imager mode by decoupling the image acquisition and readout rates.

In the future, we hope to fabricate a newer version, DSAD4, Figure 4c, that will have 512x512 pixels, and will contain all the logic necessary for control and interface functions.

**Figure 4a. DSAD2**

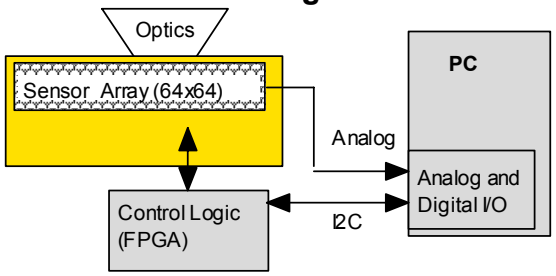



**Figure 4b. DSAD3**

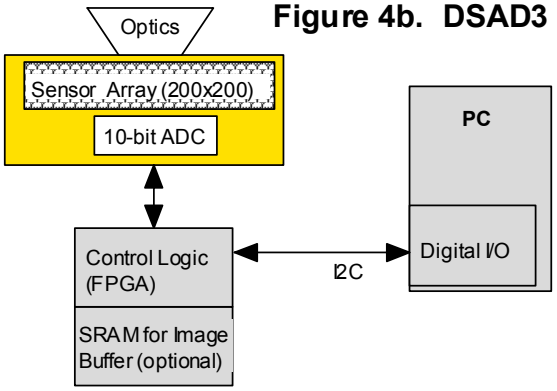



**Figure 4c. DSAD4 (future)**

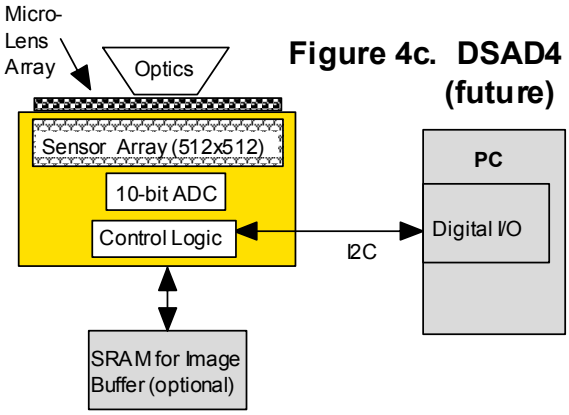



**Figure 4.** µDSAD configurations.

Due to a lack of funding, we have not been able to consistently characterize each version of the chip under all radiation, lighting, or test conditions. However, since the basic design of the array and logic elements is unchanged, the results should be similar from one version to the next.

Figure 5 presents pre-radiation position sensing test results for one of the DSAD2 prototypes. The results were obtained by scanning a large laser spot across the surface of the detector, and monitoring the resulting outputs. Since the DSAD2 part does not have an internal A/D converter, we processed the X and Y analog outputs with a PC-based analog-to-digital converter. In both cases, we could resolve position to better than 1 µm for a large laser spot (1 part in 1344). The measured resolution was limited by our position stage resolution of 1-µm steps. In our test setup, the beam was scanned across the horizontal axis; the slight drift in the vertical axis response was due to the fact that there was a slight vertical component to the beam scan direction. The nonlinear response at the ends of the horizontal and vertical traces result when the large spot falls partially off chip.

The apparent gain change after radiation was negligible, but we could not measure absolute offset shifts with our measurement equipment. (We are now preparing to make such measurements on the DSAD3 chip). It is clear, however, that the basic position-sensitive active-pixel method is quite radiation tolerant, and has sufficient accuracy for a wide range of applications. A second DSAD2 chip was dosed to higher than 300 krad (results restricted for International Traffic in Arms Regulations [ITAR] purposes) and exhibited no apparent

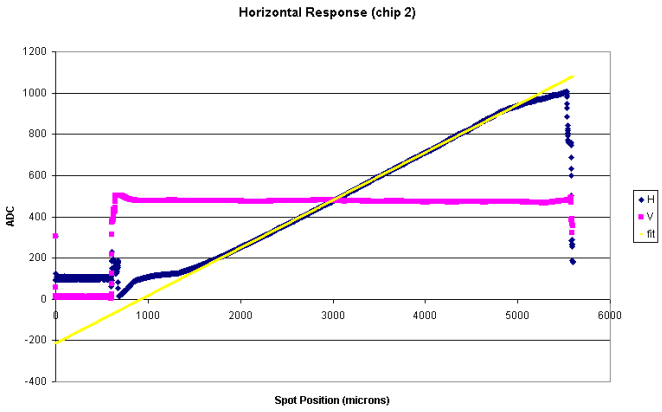



**Figure 5.** ADC Output vs. Spot Position

performance degradation. This test data on the DSAD2 test chip show that the annular NMOS layout technique results in very good total dose immunity with the AMI C5N process. The DSAD2B and DSAD3 chips was both tested for SEL at Brookhaven National Laboratory, and found to be SEL immune for an Linear Energy Transfer (LET) of 120 MeVcm$^2$/mg. The DSAD3 chip was also tested at Indiana University for susceptibility to high energy proton damage; no degradation was seen after a fluence of 1x10^11 protons/cm^2.

Figure 6 presents an actual solar transit of the DSAD2B prototype. This data was collected by simply situating our test setup in an open field and exposing the test device to the Sun. Data was once again collected using the PC-based A/D converter. Test results are quite good; the detector response remained very linear throughout the ~2 hour test.

Figure 7 is a 200 × 200 pixel housekeeping image of a "Beverage deployment" taken in our lab with the DSAD3 chip. The picture demonstrates the ability of the µDSAD to take monochrome images (the few apparent bad pixels are actually dust on the array). This image was acquired using the same optics as was used for the solar-transit measurement. We expect that monochrome images such as this can be used to monitor spacecraft deployments, etc.

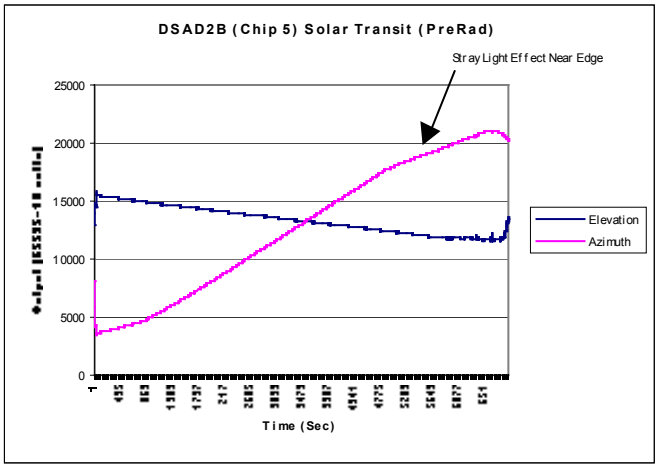



**Figure 6.** Solar Transit of µDSAD.


**Figure 7.** Sample Image Acquired by 200 x 200 array DSAD3 chip

Primary funding for this effort came to a close on December 31, 2000 when funding for the NASA Advanced Technology Development program at JHU/APL ended. We have been able to continue this work at a reduced level through a small internal development grant at APL and through a small development contract from Goodrich. The funding picture after approximately Oct 1 of 2001 is unclear.

## Limitations in the Present Design

Several factors that limit the performance of the devices we have produced to date. These restrictions are:

1) Limited fill factor of the detectors as related to the array size. Figure 8a is a die photograph of the DSAD2 prototype 64x64-element active-pixel array. Figure 8b shows an enlarged section of the die; the small dark squares are the active detector areas of the pixels. Each detector requires a certain amount of support circuitry to perform the diode readout and centroiding functions. We also need to maintain some separation between the detector elements and the other circuitry to avoid bias problems (this problem was fixed between the DSAD2 and DSAD2B versions). As a result of this overhead, the active detector area occupies only about 5% of the area

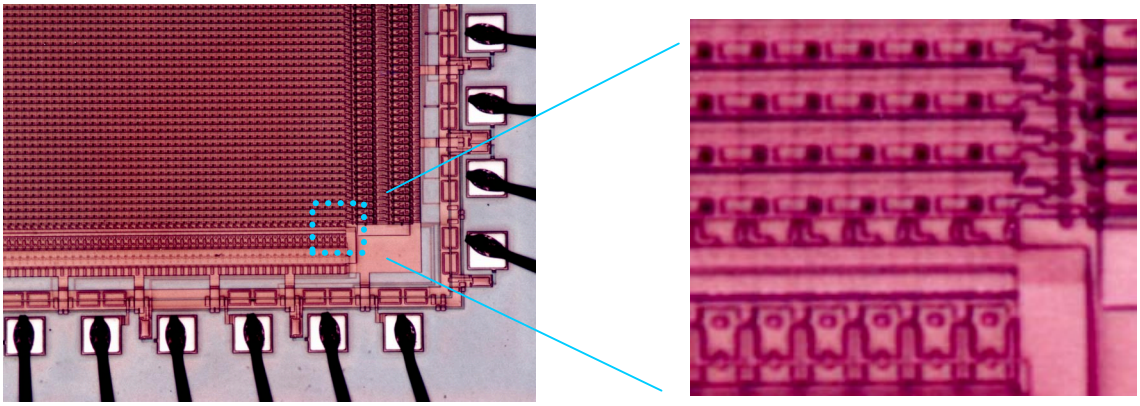


**Figure 8a and 8b.** µDSAD Prototype Die Photograph and Enlargement.

required for each pixel element. This limits both the overall photon efficiency of the detector, as well as its ability to measure small optical elements of an image (such as stars). The detector element design is unchanged in DSAD3.

2) The internal ADC is good to only 10 bits resolution, and thus it presently limits the overall resolution that is available across the array to 1 part in 1024. The differential non-linearity of the ADC is 0.3 LSB over temperature. There is a minor gain shift over temperature, but since the DSAD and imaging are somewhat immune to this effect (due to ratiometric scaling), this is not a problem.

3) The response to the overall DSAD sensor may not be ideal across the whole FOV, due to imperfections in the optics, edge effects, etc. It is, therefore, desirable to include margin in the system design and have the spot size larger than the pixel size.

4) The present design FOV is limited by the detector array size. To achieve the finest sub-pixel resolution, the optics must be selected so that the solar image fills at least two pixels. The present array size is 200x200 pixels. This is sufficient for restricted FOVs, but is not adequate for FOVs greater than ~±40°. At 1 AU, the Sun is approximately 0.5° across. At larger view angles, the size of the Sun on the array would be comparable to the size of a pixel (100° ÷ 200 elements). Our testing has shown that defocusing the image on the array should improve the DSAD resolution, thus alleviating this problem somewhat. Such defocusing is obviously not desirable for imaging mode, however. It is clear that the array size must be increased to simultaneously achieve both a large field of view and a fine resolution.

## Proposed Future Efforts

To address the issues raised above, we hope to investigate several improvements to the µDSAD design, The areas of study are:

1. Add a microlens array in front of the detector array. The array would be sized such that each microlens is the size of a complete pixel on the µDSAD. As shown in Figure 9, the light collected by each lens would be focused onto the active detector area of each pixel, thus improving the overall optical efficiency and eliminating the "detection deadzones" for each pixel. Microlens arrays such as this are commercially available; we propose to investigate whether use of the devices is practical and beneficial in

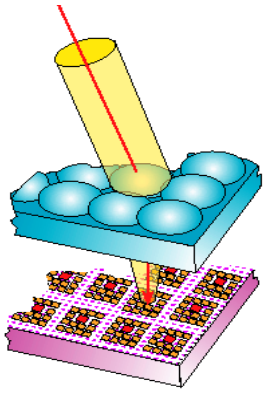


**Figure 9.** Simplified Microlens Optics (Courtesy Goodrich).

this application (including their radiation tolerance).

2. Based on a detailed measurement of the existing internal ADC design performance, we will implement circuit changes (such as improved amplifier linearity and comparator speed/sensitivity) with the goal of providing 12 to 13 bits measurement resolution. Prototypes of this improved ADC are presently being fabricated.

3. Implement a "sub-ranging" capability to the ADC measurement such that the full ADC measurement range can be applied across a subset of the full pixel array. This provides an effective higher resolution measurement, albeit over only a smaller portion of the array. For example, if the existing 10-bit ADC range were used to measure the centroid signal produced over just one-quarter the linear size of the array in either direction, this would yield four times better resolution. In a two-step process, the subrange area could be selected and measured after the whole array had first been processed to determine where the Sun was located. Since the position measurement process requires less than 1 msec, this should present no time alias problem.

4. Increase the size of the area from its present 200 × 200 pixel design to 512 × 512 pixels. This would increase the application specific integrated circuit (ASIC) die size, and thus cost (by approx. a factor of four), but would not appreciably alter the operating characteristics of the detector elements or the overall required power.

## Flight Demonstration

We will soon begin the fabrication and test of a µDSAD unit for delivery to the CONTOUR Project. CONTOUR is scheduled for a July 2002 launch and encounters with comets Encke (in 2003) and Schwassman-Wachmann 3 (in 2006). The mission may also include a flyby of comet d'Arrest in 2008 or a yet-to-be-discovered comet.

The project management has agreed that the µDSAD unit would be considered a technology demonstration, and as such, would not be required to follow the usual chain of reviews, configuration control, etc. that most flight hardware is subject to. The µDSAD will, however, receive such scrutiny in later phases of its development. We will be required to demonstrate that the µDSAD hardware does not present an electrical or mechanical threat to the mission or any of its hardware. This will be accomplished through the use of simple electrical fault isolation (e.g., series resistance on power and signal interfaces) and minimal vibration testing. We will also submit materials lists to the project to ensure compatibility with requirements.

The flight unit must be delivered to the CONTOUR Project early in FY2001. The CONTOUR Project has agreed to provide an I2C interface and +5 V power connection; both were already baselined in the hardware design on an existing test connector. The I2C bus will be dedicated to the µDSAD; no other users are affected. The data from the sensor will be collected by one of the instrument processors and inserted in a packet; no other on-board data processing will be necessary.

CONTOUR has further agreed to mount the sensor in a suitable location to view both the Sun and the Earth during early mission operations. The µDSAD assembly will act as a balance mass on the spacecraft, and will be situated on the spacecraft's top deck where such mass is required. There are no thermal or mechanical interface issues.

CONTOUR will be responsible for adding the new data interface software and to modifying their own mechanical and electrical drawings to reflect this the µDSAD inclusion. No direct support will be provided, however, to help fabricate, test, or deliver the µDSAD sensor. APL has made available a small internal development grant to help defer the parts costs.

Given the small amount of hardware in question and the limited reliability requirements, we feel confident we can deliver a flight-ready µDSAD sensor within the available budget and schedule.

As seen in Figure 10, we plan to fly two copies of the DSAD3 chip; one will employ a simple lens for focusing light onto the array, and the other will employ simple pinhole optics. Both sensors should demonstrate operation under flight conditions of the important elements in the design. We plan to compare the results obtained from these two approaches, and use them for selecting future flight configurations. This approach allows us to verify:

1. The suitability of the optics, including the off-axis light rejection, non-linearities, etc.
2. The sensitivity, anti-blooming, and centroiding capability of the detector elements; the pixel/detector elements, readout logic, and analog processing would all use the expected final design.
3. The ability to communicate with the spacecraft via the I2C communications path
4. The end-to-end performance of the Sun sensor measurement. Results can be compared to those obtained from the CONTOUR spacecraft's other Sun sensors and star cameras.
5. The ability to take and readout engineering-quality images using the Earth and possibly several comets as subjects.

While this flight opportunity would not allow us to test a final flight-ready commercial product, it would allow us to verify the most important elements in the design in the first 3 months of operation. The early flight opportunity will allow us to implement corrections or improvements while the program is still active, thus ensuring that the end result is appropriate for use on other missions. The µDSAD apparent solar position will be compared with the derived position based on the independent CONTOUR spacecraft attitude system (100 µrad attitude knowledge). The µDSAD positions can be evaluated for accuracy as a function of total radiation dose, aging, and exposure to UV photons. Repeated housekeeping images of the Earth, moon, and stars can be evaluated to determine the image-sensing performance as a function of the radiation environment. Spare analog inputs on the µDSAD chip will be used to monitor an internal temperature sensor and a RadFET (Radiation Field-Effect Transistor) to help correlate sensor performance with temperature and total radiation dose.

## Commercialization Efforts

We are presently working under a small contract with Goodrich Aerospace to perform a series of tests to document acceptable performance under conditions of radiation, thermal extremes, interface noise, varying illumination conditions, etc. These results will be evaluated by Goodrich, and hopefully lays the necessary groundwork for transitioning the complete design to them for eventual commercial fabrication.

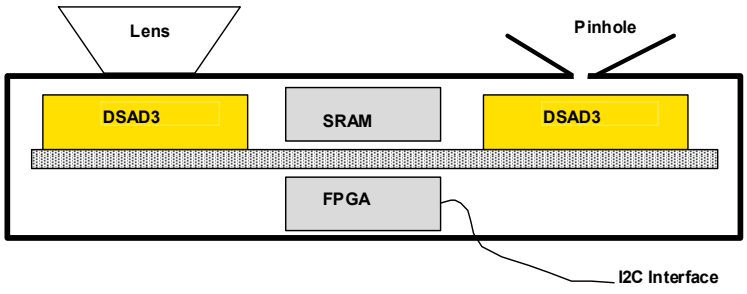



**Figure 10.** CONTOUR Demonstration Configuration

## Summary of Design Status and Development Plan

The existing DSAD design has excellent temperature, radiation, and latchup test results. We have demonstrated the ability to measure the Sun's position as well as the imaging mode (see Figure 7). The resolution has been determined using a visible red laser spot in the lab to be better than 1 µm (1/21 pixel).

To achieve the finest sub-pixel resolution, the optics must be selected so that the solar image fills at least two pixels. At 1 AU the Sun subtends 0.5º, so we see that the array size determines the field of view. If the Sun fills two pixels at 1AU, our DSAD3 design is expected to achieve 0.05º resolution over a ±25º field of view. In this case, the resolution is limited by the 10 bit on-chip ADC. For the case where the Sun fills only 1 pixel, the DSAD3 should provide 0.5º resolution within a ±50º field of view at 1 AU.

The µDSAD sensor will require only 20 mW to operate in the DSAD mode, and 100 mW (assuming an external SRAM) in the imaging mode. The sensor is predicted to weigh approximately 100 grams, and will not require any external hardware to process the position information. These should be compared with the current state of the art; a Sun sensor that has a ±64° FOV with 0.03° accuracy requires approximately 1.75 W of power and 1900 grams (sum of the electronics box and two sensors).

We plan to demonstrate the flight performance of this technology by flying on the CONTOUR spacecraft. The results from the µDSAD hardware can be compared with on-board commercial DSADs.

Future designs employing improved electronics, a larger detector array, and a micro-lens assembly are proposed. These efforts will be worked in partnership with Goodrich Aerospace.

Figure 11, generated by Goodrich Aerospace, shows a conceptual exploded view of a flight configuration µDSAD sensor. The sensor shown utilizes a lens assembly to focus the light. A similar view could show the same assembly with pinhole optics instead of the lens. The final choice between these two approaches will be made based on the results of our development testing and the particular application for which the sensor would be used (Sun sensor only or imaging option).

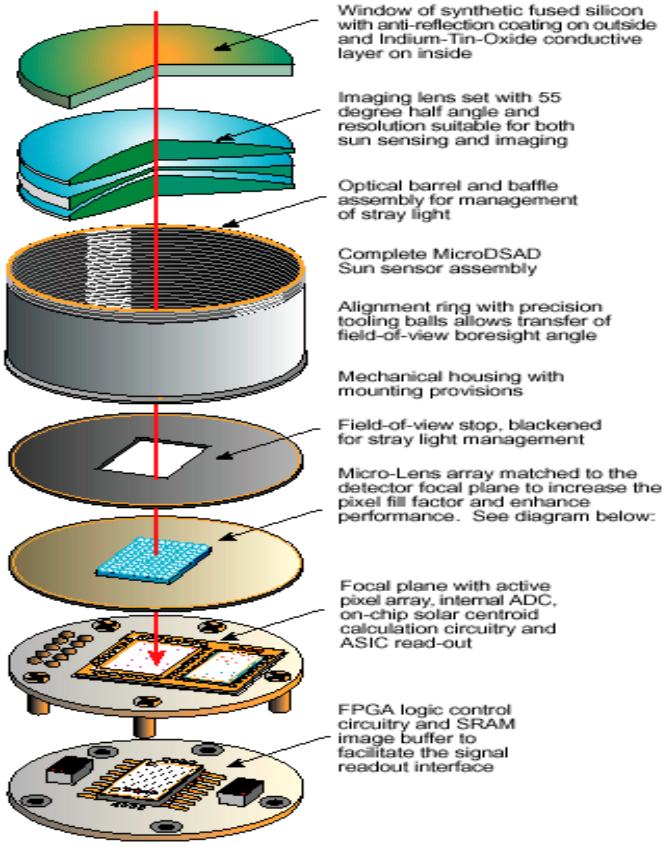



**Figure 11**. Conceptual view of the proposed µDSAD sensor construction (Courtesy Goodrich).

## Acknowledgements

This work has been made possible through a grant from the Johns Hopkins University Applied Physics Laboratory Internal Research and Development (IRAD) Committee and funding from NASA's Advanced Technology Development program at the Johns Hopkins University Applied Physics Laboratory.

## References

[1] Patent number 6058223 Video-Centroid Integrated Circuit.

[2] M. Cohen and J.P. David, "Radiation Effects on Active-Pixel Sensors," Proceedings of the Fifth European Conference on Radiation and it Effects on Components and Systems, pp.450-456, Fontevarand, France, September 1999.

[3] M. N. Martin, "Integrated Circuit Design Considerations for Spacecraft VLSI implemented in Standard CMOS Processes," Ph.D. dissertation , Johns Hopkins University, March 2000.

[4] A. Giraldo, "Evaluation of Deep Submicron Technologies with Radiation Tolerant Layout for Electronics in LHC environments," PhD Thesis Submitted to Universita Degli Studi Di Padova, Dipartimento Di Fisica, 31 December 1998.

[5] S.P. DeWeerth and C.A. Mead, "A Two-Dimensional Visual Tracking Array," Advanced Research in VLSI, Fifth MIT Conference, March 1988.

[6] K. Strohbehn, R.E. Jenkins, A.G. Andreou, X.L. Sun, "Analog VLSI Video Computation Organization, ", Proceedings of Government Microcircuit Applications Conference, pp.585-588, November 1992.

## Biographies of Authors

STEPHEN E .JASKULEK earned a B.S. in electrical engineering from Washington University in 1979 and an M.S. in computer science from The Johns Hopkins University in 1985. He is a member of the APL Principal Professional Staff. Since joining the Laboratory in 1981, Mr.Jaskulek has worked as a system engineer in the Space Department on a number of particle measurement instruments. He continues to support the operation of instruments on the Galileo, Cassini, Geotail, and Image spacecraft. He is also involved in the development of miniature advanced electronics for space systems. His e-mail address is stephen.jaskulek@jhuapl.edu.

KIM STROHBEHN obtained a Ph.D. in electrical engineering from Iowa State University in 1979 and joined APL that same year. He is currently a Principal Staff engineer in the Space Instrumentation Group. His primary interest is mixed signal analog/digital VLSI design for advanced astronomical and space instrumentation. His e-mail address is kim.strohbehn@jhuapl.edu.

MARK N.MARTIN is a Senior Professional Staff engineer in APL 's Space Department. He received a B.S.E. in electrical engineering from Southeastern Massachusetts University in 1991, and an M.S.E in 1993 and Ph.D. in 2000, both in electrical engineering, from The Johns Hopkins University. Dr. Martin's research interests are mixed signal analog/digital VLSI design,integrated sensing systems, and radiation effects in electronics. He specializes in the design of ASICs for use in space fabricated with commercial foundries. He is a member of the IEEE. Dr.Martin's e-mail address is mark.martin@jhuapl.edu.