COOLED SLOW-SCAN PERFORMANCE OF A 512 × 320 ELEMENT CHARGE-COUPLED IMAGER*

R. L. Rodgers III and D. L. Giovachino
RCA Corporation
Electronic Components
Lancaster, Pennsylvania

A 512 × 320 element charge-coupled imager has been fabricated and tested under cooled slow-scan conditions to evaluate the device's performance under a variety of long integration and slow-scan readout conditions. Operation in a low-blooming mode of operation enables the sensor to be exposed with portions of the image heavily overexposed, without those areas spreading into adjacent picture areas. This paper describes the device design, layout, and operating mode, and presents experimental results, including displayed images taken under cooled slow-scan operation.

A 512 × 320 element imager based on charge-coupled device (CCD) technology has been fabricated for use in a variety of television applications, including those applications requiring slow-scan operation. The choice of this cell count has been described previously (Ref. 1). This device utilizes a single-layer doped polysilicon gate structure (Ref. 2). The individual gates are formed by doping N^+ regions in a P-layer of polysilicon on top of the channel oxide. This results in low leakage between gates. Since there are no exposed gaps, a stable sealed channel structure results. The polysilicon layer is transparent to most wavelengths, and there are no opaque areas to cause aliasing. The useful spectral response range extends from 420 nM to 1100 nM (Ref. 3).

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The device is organized into a three-phase vertical frame transfer system (Ref. 3). N-surface channel operation is utilized. An electrical bias charge (fat zero) is inserted into the horizontal register to improve horizontal resolution. An optical bias light is used to introduce bias charge into the body of the image area.

Conventional television requirements involve observation of objects in motion in real time in a similar fashion to motion picture filming. This results in relatively short exposure times to avoid image motion smearing and flicker in the display. A large number of picture elements must be read out each frame at a fast readout rate to keep up with the picture rate (i.e., 30 frames/sec and a 6-MHz data rate). In many scientific imaging applications, the requirement to record, transmit, or process video at high data rates presents a problem. In those applications where a single frame of video is sufficient, slow-scan readout may be used following an exposure to reduce the data rate. Also the exposure time may be lengthened to expose faint images, as is done with film. Both of these techniques place severe requirements on the dark charge generation rate and signal handling capability of the sensor. Buried-channel devices have experimentally exhibited smaller signal handling capability and higher dark current generation rates than surface-channel devices. This has led to the choice of a surface-channel structure for the 512×320 element sensor being described. Sensor cooling is required for very slow readout rates and/or long exposure times to reduce the thermal generation of dark current. The device is packaged in a hermetic, edge-contacted, 24-connection ceramic dual in-line package. The package contains an optical glass window to allow the image to be focused onto the sensor. The packaging has a low thermal impedance to the chip and facilitates easy cooling.

There is no residual image remaining after the picture has been read out. This means that no special prepare or erase cycles are required for proper slow-scan operation. All that is required is proper setting of the exposure. The sensor is normally operated in a run-stop-run mode of operation for slow scan. The sensor is set up to operate at the desired readout rate and is left continuously reading out the dark signal until it is desired to make an exposure. The vertical clocks are stopped during the time the shutter is open to expose the image. After the shutter is closed, the slow-scan readout at the preset rate begins. The horizontal clocks are kept running during the exposure to read out any dark or light charge buildup in this register.

Many scenes are low contrast and do not present small area overload problems to the CCD sensor. Other scenes may contain strongly overloaded areas (e.g., star fields). Containment of charge during overloads can be a problem with CCD imagers. Figure 1 shows the performance of the 512×320 sensor operating in its low-blooming mode of operation (Refs. 3, 4). All of the small circular images in the scene are 0.25 mm in diameter on the sensor. The one on the right center is exposed at saturation and represents the original image size. The image at the upper left is at a 10X overload. The remaining four images are at a 100X overload. It can be seen that the image size grows less than a factor of two in diameter with this 100X overload. Part of the enlargement is known to be from the lens itself.

Figure 2 shows what would have happened if the low-blooming mode of operation had not been used. The blooming takes place in the vertical direction because it is confined by the channel stop diffusions in the horizontal direction. The low-blooming mode of operation is accomplished by accumulating the substrate under the two-phase gates next to the phase gate collecting charge during picture exposure. This electronically extends the channel stops around each sensing site, preventing charge spreading. The sensor's phase gates are then biased into depletion during the normal readout transfers. Buried-channel devices cannot use this method of charge confinement during exposure since the surface cannot be accumulated (Ref. 2). This was another reason for choosing a surface-channel structure instead of a buried-channel structure for this 512×320 sensor.

The pictures shown in Figures 1-6 were all taken with a 10-second picture frame readout time. The sensor was cooled to -6°C for all of the pictures. All of the pictures were made in the low-blooming mode of operation except Figure 2, in which blooming was allowed to occur to demonstrate the effectiveness of blooming control. Figures 3 and 4 show live imaging of the authors. Figure 3 was taken with a 1/4-second exposure. Figure 4 was taken with a 2-second exposure. Figures 1, 2, and 5 were taken with a 30-second exposure, followed by the 10-second readout. Figure 5 is a picture of two different star fields taken from a book. The white line in the middle is the division between the two pages of the book. Figure 6 is a picture of the earth. It was exposed for 67 seconds, followed by a readout of 10 seconds. The equivalent illumination on the sensor in the highlights is approximately 5×10^{-5} - 1×10^{-4} fc of 2856-K illumination. The sensor was measured to have a dark current density of 2 nA/cm^2 at 24°C. The sensor exhibited cell-limited resolution in all parts of the picture (i. e., 512 × 320 cell resolution). However, the Tektronix 604 display used for the pictures cannot resolve individual raster lines. All of the photographs exhibit a horizontal line structure. This is not generated by the 512 × 320 imager. This background pattern is present in the display even when the video is disconnected and varies with scan rate. It is believed to be due to 60-cycle modulation in the 604 display unit.

Figure 7 shows a portion of one video line of information at the output of the imager (16-kHz data rate, corresponding to 10-second readout). The video is shown with white negative. The output floating diffusion is reset at the end of each clock period so that the next cell output will be present for most of the next clock phase. This presents the data in a pseudo sample and hold output. No further video processing or filtering was necessary to make the displayed photos. The reset pulses that are present merely blank off the beam for a small part of an element time and are not resolved in the displayed picture.

In summary, it has been shown that a 512 × 320 element CCD imager may be operated at scan rates much slower than standard television (i. e., 10-second frame time compared to 33-msec frame time) and integrated for much longer times (i. e., 67 seconds compared to 16 msec) by slowing down the scanning and using a modest amount of cooling.

These results do not represent the limiting performance possible from such a sensor even at this temperature as regards frame time and integration time. The ultimate performance will be limited by the dark current generation rate at the lowest operating temperature.

REFERENCES

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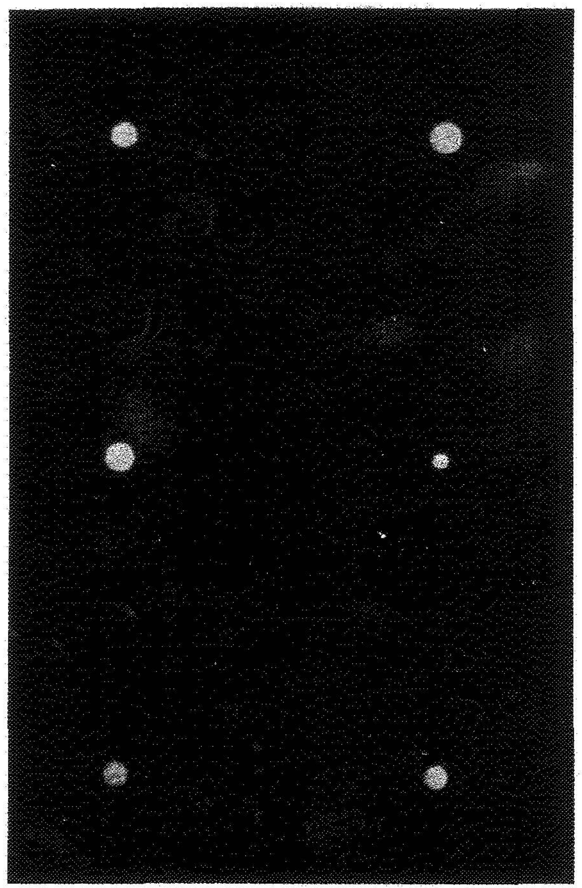

Figure 1. Low-blooming imaging of 0.25-mm images (10-sec readout, 30-sec integration, -6°C temp.)

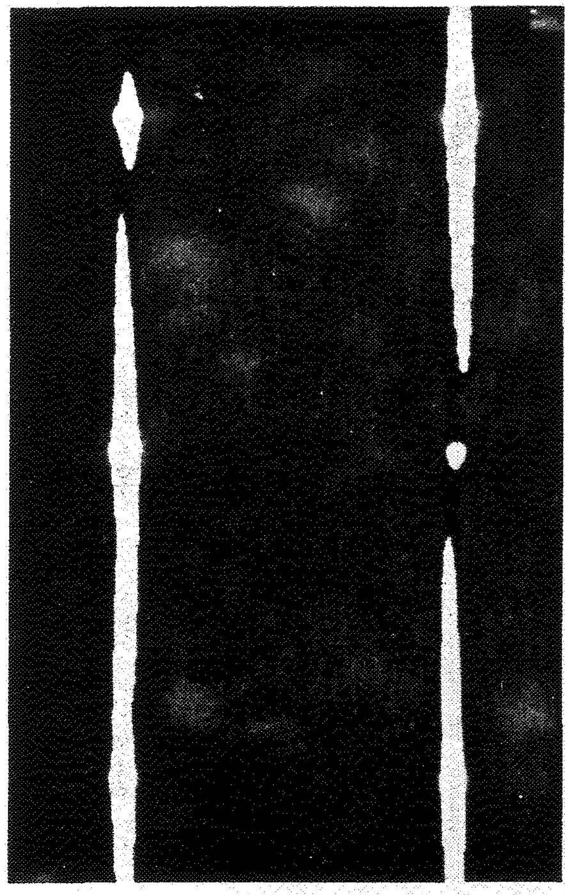

Figure 2. Blooming imaging of 0.25-mm images (10-sec readout, 30-sec integration, -6°C temp.)

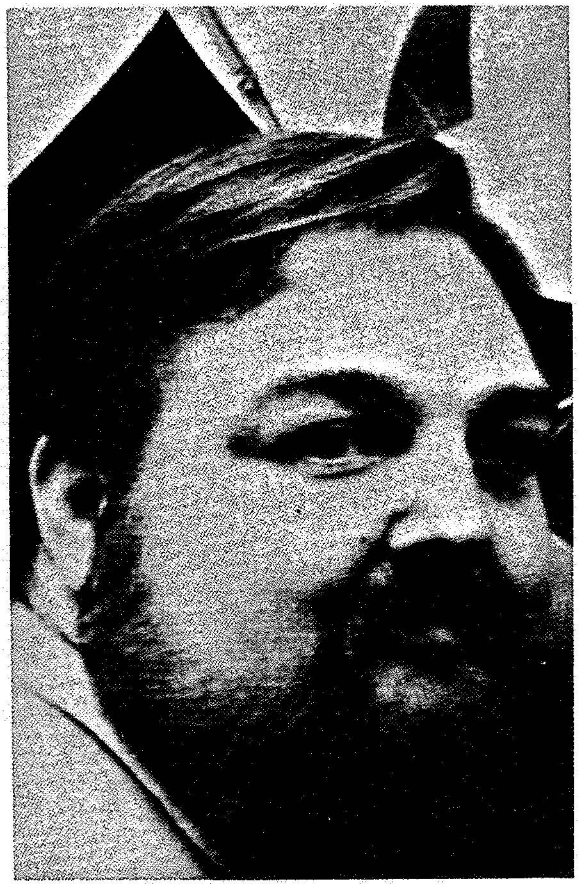

Figure 3. Live imaging of R. L. R. (10-sec readout, 1/4-sec integration, -6°C temp.)

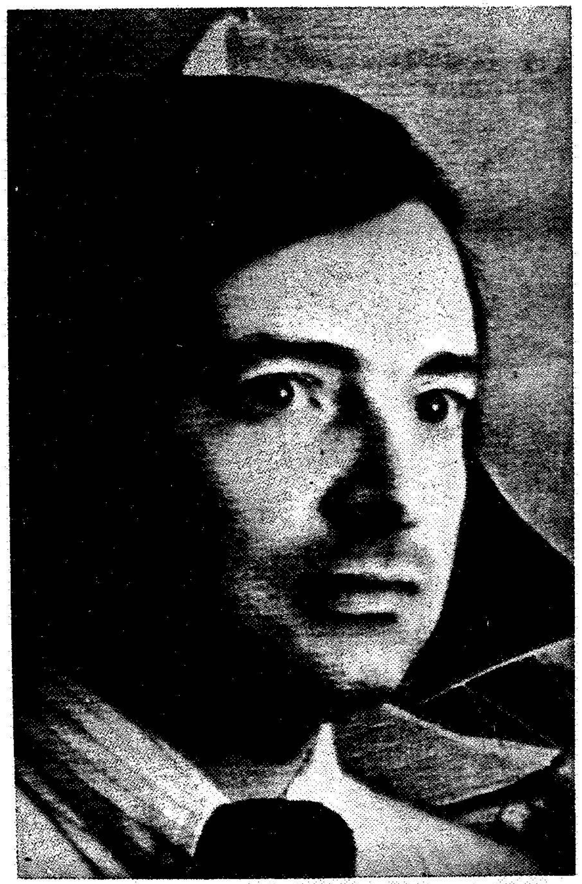

Figure 4. Live imaging of D. L. G. (10-sec readout, 2-sec integration, -6°C temp.)

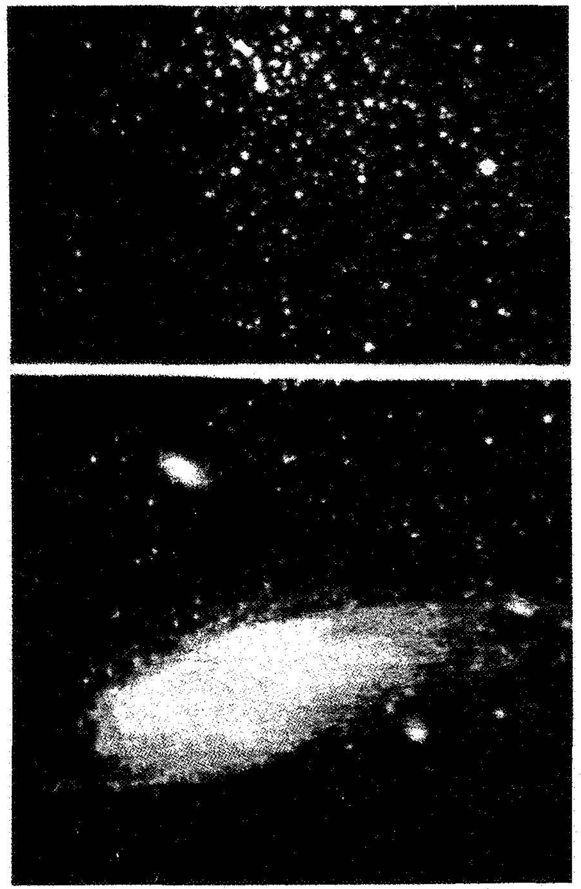

Figure 5. Star field imaging (10-sec readout, 30-sec integration, -6°C temp.)

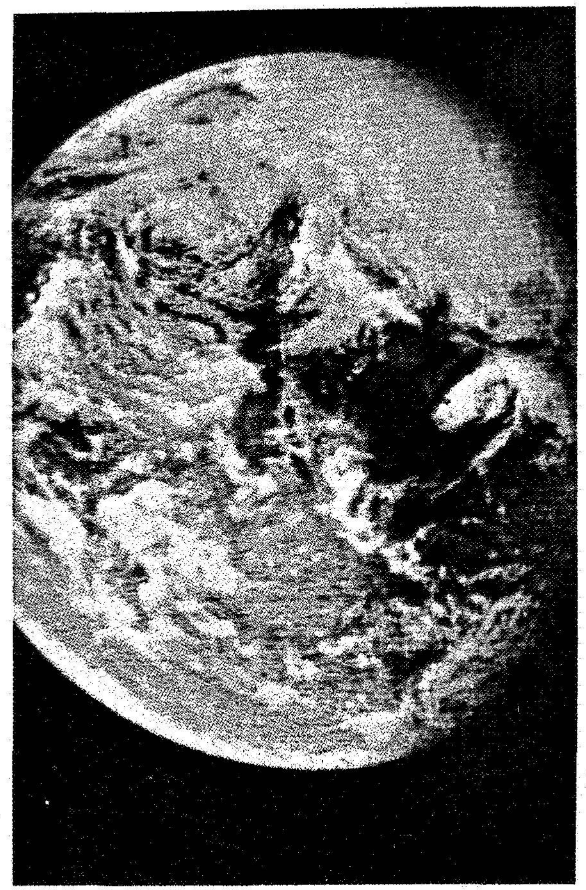

Figure 6. View of earth (10-sec readout, 67-sec integration, -6°C temp.)

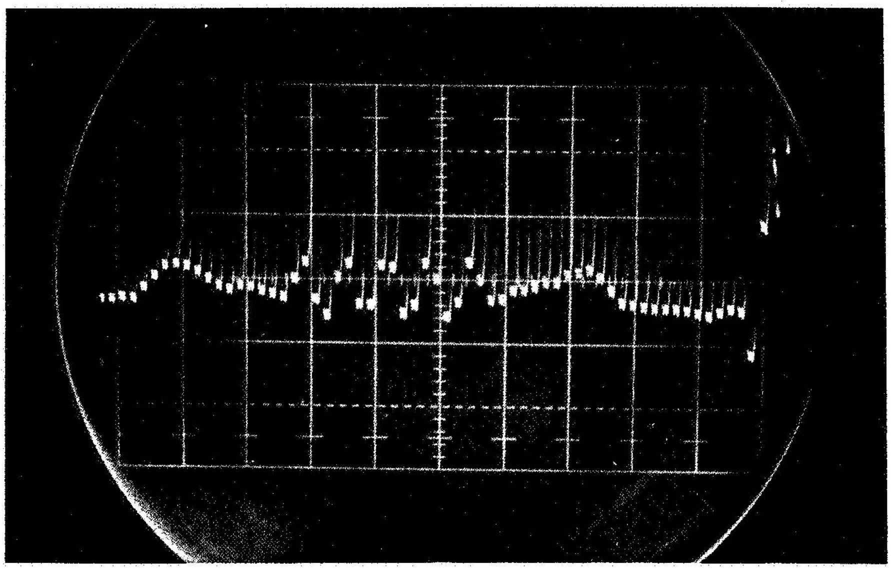

Figure 7. Expanded video output (white negative, 16-kHz data rate, 10-sec readout)