23 August 1976

Reticon Information Summary

I. Devices of Interest and Specifications Given by the Manufacturer.

Of the many Reticon linear self-scanning photodiode arrays currently available, the only ones of potential usefulness for the VLA optical processor are the B and C series, and possibly the EC series with a special tooling to produce a 50.8 μm x 50.8 μm effective area per photodiode. We should a look at the RL-1872F, despite the unhandy length for making 4000 x 4000 array and the rectangular effective diode area (15 μm x 16 μm), because of the overall reduction in the size of the output plane obtained compared to the B or C series devices.

All of the above devices suffer from a dark current tha typically is ≲ 1 pA per diode at 300°K and which decreases a factor of 2 for every 7 to 10°K decrease in temperature.[1,2] They all have a maximum clock repetition rate of 10 MHz (but differing maximum data rates due to different output configuratio and they all suffer from "switching transients" on the video lines due to clock pulses feeding through the parasitic capacitance between clock lines and the video. There are also transients due capacitive feed-through from the MOS FET gates to the video as the diodes are sequentially accessed by the shift registers.

Before reviewing the experiences of others who have attempted to implement Reticon arrays, it is desirable to catalog the specificati as supplied by the manufacturer, to give a point of reference. The data found in Table I below come from, or are calculated using numbers that come from the appropriate data sheets,[2,3,4] with-B series specifications being updated, when possible, from a more recent Reticon "product summary."[5] All values are t be taken as typical, at a temperature of 25 °C, with th video lines biased at -5 volts relative to array common.

The EC devices, with a special tooling to make the aperture 50.8 μm, would have the following *approximate* specifications (see Table I for definition of terms) under the same conditions a given above:

Q_{sat} : 4 pcoul
l : 50.8 μm
W : 50.8 μm
a : 2.58×10^{-5} cm^2
$S(6328\ \text{Å})$: 8.3 $\frac{\text{pA cm}^2}{\mu\text{watt}}$
$S(5000\ \text{Å})$: 5.3 pA cm^2/μwatt
$\xi(6328\ \text{Å})$: 0.63
$\xi(5000\ \text{Å})$: 0.51
$E_{sat}(6328\ \text{Å})$: 0.48 μjoule/cm^2
$E_{sat}(5000\ \text{Å})$: 1.5 μjoule/cm^2
DC Power Dissipation: 1.5 mwatt
Number of video lines: 1
Number of clock phases: 2
Maximum data rate: 10 MHz
Dimensions of a 4000 × 4000 array of contiguous photoelements } 20.3 cm × 20.3 cm = 413 cm^2

The remaining 3 characteristics in the table, uniformity of sensitiv to 2870 °K Tungsten light and video and clock line capacitances are

Tab I

	RL512B	RL1024B	RL256C	RL512C	RL768C	RL1024C	RL1872F
Saturation Charge: Q_{sat}	4.6 pcoul	4.6 pcoul	4.0 pcoul	4.0 pcoul	4.0 pcoul	4.0 pcoul	3.2 pcoul
enter-to-center diode spacing: λ	25.4 μm	25.4 μm	25.4 μm	25.4 μm	25.4 μm	25.4 μm	15 μm
Aperture width: W	25.4 μm	25.4 μm	25.4 μm	25.4 μm	25.4 μm	25.4 μm	16 μm
Effective photon collectio rea per diode: $a = \lambda \cdot W$	6.45×10^{-6} cm²	6.45×10^{-6} cm²	6.45×10^{-6} cm²	6.45×10^{-6} cm²	6.45×10^{-6} cm²	6.45×10^{-6} cm²	2.4×10^{-6} cm²
hotodiode Sensitivity it $\lambda = 6328$ Å: $S(6328\,Å)$	$2.6 \frac{pA\,cm^2}{\mu watt}$	$2.6 \frac{pA\,cm^2}{\mu watt}$	$2.6 \frac{pA\,cm^2}{\mu watt}$	$2.6 \frac{pA\,cm^2}{\mu watt}$	$2.6 \frac{pA\,cm^2}{\mu watt}$	$2.6 \frac{pA\,cm^2}{\mu watt}$	$0.98 \frac{pA\,cm^2}{\mu watt}$
hotodiode Sensitivity r $\lambda = 5000$ Å: $S(5000\,Å)$	$1.7 \frac{pA\,cm^2}{\mu watt}$	$1.7 \frac{pA\,cm^2}{\mu watt}$	$1.7 \frac{pA\,cm^2}{\mu watt}$	$1.7 \frac{pA\,cm^2}{\mu watt}$	$1.7 \frac{pA\,cm^2}{\mu watt}$	$1.7 \frac{pA\,cm^2}{\mu watt}$	$0.62 \frac{pA\,cm^2}{\mu watt}$
Effective Quantum Yield $\xi(\lambda) = \frac{hc\,S(\lambda)}{\lambda a e}$:							
$\xi(6328\,Å)$	0.79	0.79	0.79	0.79	0.79	0.79	0.80
$\xi(5000\,Å)$	0.65	0.65	0.65	0.65	0.65	0.65	0.64
Saturation Exposure $E_{sat}(\lambda) = \frac{Q_{sat}}{S(\lambda)}$							
$E_{sat}(6328\,Å)$	$1.8 \frac{\mu joule}{cm^2}$	$1.8 \frac{\mu joule}{cm^2}$	$1.5 \frac{\mu joule}{cm^2}$	$1.5 \frac{\mu joule}{cm^2}$	$1.5 \frac{\mu joule}{cm^2}$	$1.5 \frac{\mu joule}{cm^2}$	$3.3 \frac{\mu joule}{cm^2}$
$E_{sat}(5000\,Å)$	$2.7 \frac{\mu joule}{cm^2}$	$2.7 \frac{\mu joule}{cm^2}$	$2.4 \frac{\mu joule}{cm^2}$	$2.4 \frac{\mu joule}{cm^2}$	$2.4 \frac{\mu joule}{cm^2}$	$2.4 \frac{\mu joule}{cm^2}$	$5.2 \frac{\mu joule}{cm^2}$
niformity of Sensitivity o 2870 °K Tungsten light	±10%	±10%	±5%	±7%	±9%	±11%	±12%

23 August 1976

WR

Table - cont'd

23 August 1976

	RL 512 B	RL 1024 B	RL 256 C	RL 512 C	RL 768 C	RL 1024 C	RL 1872 F
DC Power Dissipation	4 mwatts	4 mwatts	3 mwatts	3 mwatts	3 mwatts	3 mwatts	4 mwatts
Capacitance of Each Video Line to Common	48 pF	100 pF	25 pF	50 pF	75 pF	100 pF	65 pF
Capacitance of Each lock Phase Line to Common	~60 pF (?)	~120 pF (?)	30 pF	60 pF	90 pF	120 pF	100 pF
Number of video lines	4	4	2	2	2	2	4
Number of clock phases	2	2	4	4	4	4	4
Maximum data rate	40 MHz	40 MHz	10 MHz	10 MHz	10 MHz	10 MHz	20 MHz
Dimensions of a 4000 x 000 array of contiguous photoelements	10.2 cm x 10.2 cm = 103 cm^2	10.2 cm x 10.2 cm = 103 cm^2	10.2 cm x 10.2 cm = 103 cm^2	10.2 cm x 10.2 cm = 103 cm^2	10.2 cm x 10.2 cm = 103 cm^2	10.2 cm x 10.2 cm = 103 cm^2	6.0 cm x 6.4 cm = 38 cm^2

HR

23 August 1976

approximately the same for the two devices listed on the same lines below:

RL512EC ;	RL1024C
RL384EC ;	RL768C
RL256EC ;	RL512C
RL128EC ;	RL256C

There is a definite reason for the curious lack of any list of "dynamic range," "S/N ratio," or the like. The obtainable values depend strongly on the scan and readout electronics use The best thing to do in this regard is to see what various users o the devices have been able to obtain.

II. Device Characteristics Reported by Others.

The last four years have seen several applications of Reticon linear self-scanning photodiode arrays of interest to us. Below I summarize the relevant points expressed by the authors about their attempts to do more or less quantitative intensity measurements using Reticon devices.

A. Early Work

There are reports of the use of several nameless Reticon 256 element linear arrays in the years 1972 and 1973. Riegler and More[6] tell of a UV and X-ray photon detector, which accelerates the seconda emission charge packets from a chevron microchannel plate into a phosphor layer coupled to the array via fiberoptics. Also, a prototy of the "self-scanned Digicon"[7] (more on Digicons later) was built using a 256 long array, as was a spectrometer described by Horlic and Codding.[8] None of the authors explicitly state the device mo

23 August 1976

number in its entirety, but I surmise each of the three groups was talking about a RL256A or a RL256E, both of which a now obsolete designs and no longer available.

Only Horlick and Coddings' work is worth pursuing in any more detail. They operated their uncooled "RL-256/128", as they called it, at clock rates between ~250 Hz and 35 kHz using reado circuitry from Reticon (circuit RD-1). Measurements of the linearity of output versus exposure were attempted for two configura In the first, while light intensity was kept constant, exposure was varied by changing integration time in a known way. For each valu of the integration time, the gain on the preamp was adjusted such that if the response of the array itself were linear, the result plot of amplified output signal versus integration time would be flat. This was done for 3 intensity levels, with integration times ranging from 20 msec to ~800 msec, at which point the combination of signal and dark current began to saturate the diode A linear least squares fit to the 3 plots resulted in slopes of −0.0010 with std. deviation ±0.0018, 0.0012 ± 0.0017 and −0.0005 ± 0.0018. They also remarked that all three intercept had percent relative std. deviations of less than 1%. The light intensities were supplied by a hollow cathode lamp (Ne 5852 and appeared to cover a very small range: probably well under a factor of 2 (judging from the spread of integration times shown on their pl

In their second test, Horlick and Codding looked for linearity of output with respect to intensity. Neutral density filter were used to vary the intensity, and by using several integration tim they claimed to have found linearity of response over 3.5 order of magnitude in intensity. The work was done at $\lambda = 6328$ Å

23 August 1976

(He-Ne laser). The "linearity" they find apparently refers to the shape of the plot of log (output signal, corrected for dark curre versus log (% transmission of ND filters), because they give the slope of the linear least squares fit to this plot as 0.95 ± 0.01. No graph of this data, or any other details concer the measurements were given.

B. Series Devices

Next we come to cases where the B series Reticon arra were implemented.

(1) We first consider the use of a RL1024B device in a "self-scanned Digicon,"[7,9,10] in which the photodiode array records electron-hole pairs produced by the kinetic energy of photocathode-released photoelectrons accelerated into it. Althou noise considerations are somewhat different for this type of application than for the photon integration mode (due to the gain produced by the electrostatic acceleration of the photoelectrons) we can profit from some of the authors' findings.

Separate charge amplifiers were employed on each of the four video lines. It was found that the variation in the switchi transient charge pulse from diode-to-diode ran about 1% of saturation, peak-to-peak, yet the statistical variation of this transient signal on any one diode was much smaller. The switching transient signals thus formed a "fixed pattern bias" which, along with the dark leakage current, could be compensat for by subtraction, to the precision set by the amplifier readou noise and the statistical variation in the transient signal and the dark current. Because of the long integration times required, t array was operated at −76 °C. The authors found a factor of 2 change in dark current for every 9.7 °C temperature change between −76 °C and +22 °C. Diode-to-diode sensitivity variation (along with nonuniformity of response in the photocathode) were calibrated by exposing the Digicon to uniform illumination. This then, produced the set of normalization factors necessary to correct the data. Of final interest, we note the authors' observation that the residual image after readout for a given scan rate depends on the time constant of the circuit rechargi the diodes when they are being addressed by the shift registers. Th is, of course, exactly what one would expect.

(2) Of all the applications reviewed here, the next is undoubtedly the most important. Two RL512B-24 (the 2.4 signifying an aperture width of 2.4 mils) arrays were employed by Livingston, et al,[11] at Kitt Peak as the detectors in the spectrograph of their solar magnetograph. They attempted a rath thorough investigation of the photodiode arrays' photometric properties, testing 3 separate arrays in all. We note here a numb of points discussed (They biased the video lines at −5 volts relat to array common, giving a Q_{sat} = 3.3 pcoul).

(a) Their application required mechanical translation of t entire array (with resulting positioning to 1 µm). They employe a 5 mm/turn ball screw, coupled to a 200 step/turn stepping motor with a 25:1 gear reduction. The position was sensed a Heidenhain model LID 2/92.22 incremental linear encoder.

(b) Noise: The following sources of noise were discussed: amplifier noise, clock noise, shot noise from the photon flux, dar current, and amplifier current, and input loss conductance in th

23 August 1976

dielectric packaging of transistors. The uncertainty in the photon flux is the familiar square root of the number of photons "recorded" at a given diode by the deposition of the photon induced charge on the photodiode capacitance. The same relationship holds for the integrated dark signal (In this particular application, the dark signal was ~0.1% of full scale with an integration time of $\frac{1}{60}$ sec. at a temperature of +5°C). The shot noise due to amplifier input current depends on the magnitude of the input current and t time required to read out a single diode. Apparently for the circuitry Livingston, et al, used, the amp. input current was $\sim 10^{-11}$ A, so the readout time of 10^{-5} sec left them with a nois equivalent signal (NES) of ~ 25 electrons (Whenever the expression "NES" is used, it is implicit I am talking about an rms noise level).

The term "clock noise" covers several phenomena, all of which can be calibrated out or reduced to a negligible level by careful circuit techniques. Ideally, if the parasitic capacitanc between each clock line and each video line were the same, and the pairs of clock phases were truly complementary, the net induced charge on the video lines due to clock transitions would be zero. Such, of course, is not the case, because of slight clock phase mismatches and differences in the coupling capacitances. Other sources of unwanted charge pulses on the video lines are the switching voltages of the internal array MOS FET's coupling through the gate-to-drain capacitance as each photodi is accessed. All these "switching transients" result in the signal charge of each diode being accompanied by a nonzero fixed patt charge, which varies from diode to diode but is independent of

23 August 1976

signal level. The rms magnitude of this fixed pattern depends strongly on circuit layout. Livingston, et al, were able to "tune" their system until the fixed pattern bias was ~5% of saturation level.

Now, to the extent that this fixed pattern bias is constant for each diode, it can be measured and then subtracted to remove it. It must be noted, however, that clock parameter changes or noise on the clock lines will add a random component to the fixed pattern bias which can not be calibrated out. Of great importance along these lines, Livingston, et al, found that the parasitic capacitances between the clock and video lines were slightly dependent on temperature, and thus it was necessary to cool the device to +5°C and regulate the temperature to ~±1°C (along with careful circuit layout) in order to reduce this random noise component to a negligible NES of ~12 electrons.

Also mentioned briefly in the article is a noise source caused by loss conductance in the dielectric packaging materia used for commercial transistors (described by Radeka[12]). I do not claim to understand the effect, but apparently it is responsible for a noise current (not unlike resistor Johnson noise) which produced in the Kitt Peak system a NES of approximately 25 to 100 electrons. Cooling can supposedly diminish the NES by a factor of 2 to 3.

All the noise sources discussed so far (with the exception of photon noise at high exposure levels) have been rendered negligible compared to amplifier noise for the Kitt Peak detectors. Rather than take the time to go through their discussion on amplification and filtering, it is sufficient for our

23 August 1976

purposes to note that using charge amplification techniques at a clock rate of ~300 kHz, Livingston, et al, were able to obtain a NES of ~ 10^3 electrons for their amplifier. This NES varies as amplifier bandwidth to the $\frac{1}{2}$ power, but a lower limit to the NES of ~ 54 electrons occurs at about 1 kHz clock rate, at which point the noise power spectrum of junction FET's starts climbing as ~ $1/f$, havin been relatively constant at high frequencies.

One note of caution: Private communication with J. Harvey (one of the et al's; on 30 June 1976) indicates tha much of the signal processing electronics disscussed in the paper are now obsolete due to nonlinear response characteristics. Sti Harvey expressed a willingness to share with us their knowledge and experience in the area of readout electronics.

(c) Dynamic Range and Maximum S/N ratio: Thus at ~300 kHz, with a signal independent readout NES of ~ 10^3 electrons, the dynamic range (defined as mean peak signal / rm dark noise on a given diode) obtained was

$$\sim \frac{2\times 10^7}{10^3} = 2\times 10^4 ,$$

2×10^7 being Q_{sat} = 3.3 pcoul expressed in number of electrons. The peak value of the S/N ratio (mean signal/rms noise on the signal for a given diode), which occurs near saturation, must take into account the photon noise as well

$$(S/N)_{peak} \approx \frac{2\times 10^7}{[2\times 10^7 + 10^6]^{1/2}} \approx 4\times 10^3 .$$

(d) Spectral Response: Livingston, et al, found the spectra response of all three arrays tested to be comparable to a

3 August 1976

U.D.T. PIN-10D planar diffused p-i-n diode, as was to be expected from manufacturer claims.

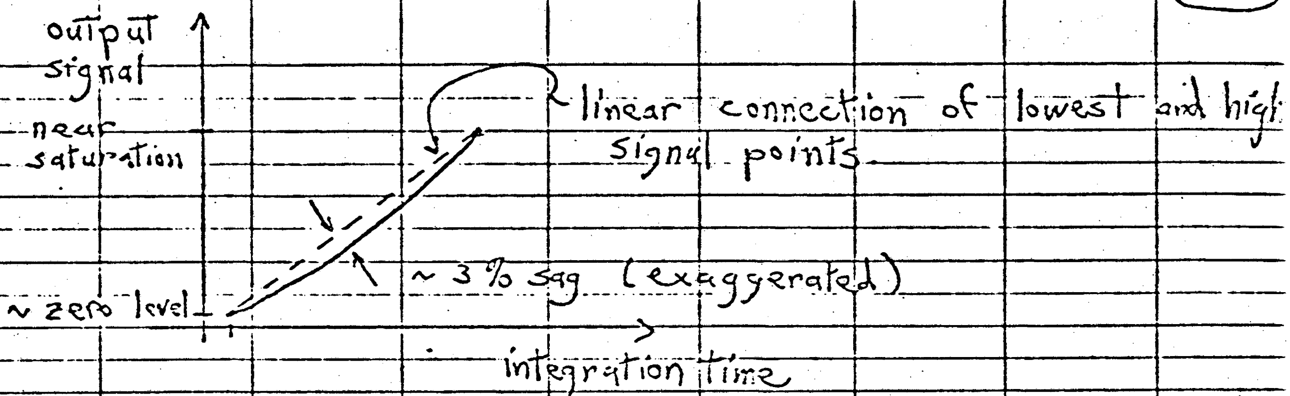
(e) Fabry-Pérot Fringing Effects: Fabry-Pérot-type interference modulation of the signal level was strongly evident in one of the three arrays tested, with a peak-to-peak fringe amplitude of ~2% (of mean signal, I guess, they do not say) and a spatial period of about 30 diodes at $\lambda \approx 6300$ Å. Both spatial period and fringe amplitude are increasing functio of wavelength, but for a fixed λ and a f/8 beam illuminating the diode array, Livingston, et al, found that, "the fringe pattern is constant and subject to removal by calibration." The other two arrays displayed less than 1% peak-to-peak amplitude fringing at all wavelengths. On talking with Harvey, it appears the now believe virtually all the fringing observed occurred in the ~0.3 mm thick quartz window, as removal of this cover glass (or replacement with a better one.) has greatly alleviated the problem. Apparently there still is a small effect due to the ~3 μm thick SiO_2 passivation layer covering the diodes, but it is not clear on exactly what level.

(f) Nonuniformity of diode sensitivity: The diode-to-diode sensitivity variation is a signal independent difference in diode response to uniform illumination found after compensation for fixed pattern bias and Fabry-Pérot effects. Livingston, et al, report a rms variation of ~0.5% for the RL512B-24 (they do not say, but I assume this is independent of wavelength). They also mention the work Hog and Wiskott[13] have done with a RL256 (again a mystery 256 element array). These workers fo an rms interdiode sensitivity variation of ~0.1%, with a 2 end-to-end variation. These variations are removable, alon with the Fabry-Pérot fringes for a given wavelength, by the determination of a multiplicative calibration constant for each diode, which normalizes all the responses to some mean sensitivity.

(g) MTF: Livingston, et al, measured the MTF for one of their arrays at various wavelengths. They conclude that for $\lambda < 7500$ Å, the array behaves essentially as if each photoelem were discrete, with uniform response over a length equal to the diode spacing (25.4 μm). Redwards of 7500 Å, lateral diffusion of carriers in the silicon degrades the MTF, because the mean photon penetration depth increases with λ.

(h) Incompleteness of Readout: For reasons unknown, the single scan readout of a saturation signal was complete only to 1.5% in the Kitt Peak system. Private communication with W. C. Livingston (6 August 1976) indicates he does not believe this is due to allowing insufficient time for the diode plus video line capacitance to recharge back to the nominal video line bias of −5 volts relative to array common.

(i) Linearity: Attempts to measure the linearity of output with respect to "input" yielded a nonlinearity, but a nonlinea response found in the amplifying electronics rendered the resul inconclusive. Although no details were given in the paper, private communication with Livingston indicates that the method use was to cool the array to a "fairly low" temperature, and then look at dark signal as a function of integration time. The results for a given diode or the average over a number of diodes typically were



More recent tests (I assume with different electronics) have been made in which a p-i-n diode was used as a reference to monitor the variation in light level from a LED source. When the output of the array was plotted against exposure as determined from the p-i-n diode and the integration time, apparently the results were essentiall the same as those above. Livingston is still not at all satisfie with their results, and considers the question of linearity unresolved.

(j) Finally, we note that in the interest of possible low-light level applications (requiring extremely long integration times), Livingston, et al, cooled a RL 512B-24 down to the temperature of LN_2 (−196°C) to see if the device would still function. To avoid heat dissipation during cooling, the array was disconnected electrically. The cooled array was the subjected to the clock signals in bursts. Operation of the shift registers was established by the occurrence of the end-of-scan pulses.

(3) Next I mention another solar magnetograph application that has occurred at Lockheed. From the sparse, and sometime confusing information given by Smithson,[14] I can only conclud he used either a RL512B or RL512C. Using a preamp followe

23 August 1976

by a charge amplifier, and operating the device at ~ −40°C, he was able to obtain a dynamic range (mean saturation signal / rms dark noise on a given diode) of ~ 2400:1, with the S/N ratio (mean signal/rms noise on that signal for a given diode) near saturation being ≳ 2000:1. Aside from reducing dark current, Smithson claimed cooling was necessary to better the S/N ratio, but he does not elaborate on this. The value for the maximum signal-to-fixed pattern bias ratio is given as ~ 50:1, but it is not said how the fixed pattern was removed (I suppose it was subtracted out). It must have been compensate for, because Smithson reports (assuming I understand his number correctly) a diode-to-diode variation in sensitivity of less than 0.07%. He calls this a "differential sensitivity," and perhaps he means this is the residual nonuniformity after not only fixed pattern has been removed, but intrinsic diode-to-diode sensitivity differences have been calibrated out. No linearit measurements were mentioned, it being apparent the author was blatantly assuming the photometric accuracy of the device. For what it is worth, a mechanical scan system was also used in this system, creating 2-D images by stepping at 1 mil intervals.

C. C Series and EC Series Devices

Finally we come to applications of C and EC series Reticon devices.

(1) Dravins, at Lund Observatory, has built a sensor for astronomical photometry utilizing a RL128EC.[15] He started with Reticon LC600 line scan camera and modified it to control exposur and sense the output video signal using current integration technique. The device was operated, uncooled, at a clock rate of 1 KHz. Dravins

3 August 1976.

found it necessary to leave the array scanning continuously, for drifts of an unspecified nature, resulted from "start-stop" operation. The combined dark signal and fixed pattern bias were found to be very reproducible for a given diode over a period of minutes, subject to a rms noise of only 2×10^{-4} of saturation level (Thus, as found above, fixed pattern bias was removable by subtraction). This noise apparently represents a readout noise, as all actual exposures, independent of level, displayed this same noise on a given diode. Note that this implies Dravins was obtaining both a dynamic range (mean saturation signal/rms dark noise on a given diode) and a maximum S/N ratio (mean signal level/rms noise on that signal for a given diode) of ~ 1400:1.

Over longer periods of time (hours), however, the dark signal displays gradual drifts which are probably due to thermal effects. Dravins found that the net result of these drifts, for a given integration time, was a change in normalization of the dark signal; i.e., a drifted dark signal differed from the original dark signal by a multiplicative constant (the same for all diodes), to the precision set by the rms noise discussed above. By maskin the first 20 or so diodes in his array, so they only recorded dark signal, and by knowing the shape of the dark signal across the whole array, Dravins found the dark signal to be subtracted from a given data scan by normalizing the standard dark signal scan so that it agreed with the dark signal on the first 20 diode that was collected simultaneously with the data. He thus avoided, he claimed, the need for temperature regulation or periodic measure of dark signal across the whole array. Although Dravins is somewh careless on this point in the text of his article, it is clear from the

the examples he gave that the fixed pattern bias is subtracted as part of the so-called "dark signal." Thus, I have followed his usage of the term "dark signal" in describing his normalizatio and subtraction process, but I think this term would be more correctly replaced by "dark signal plus fixed pattern bias."

Linearity of output with respect to exposure was measured using a constant light source, constant integration time, and neutral density filters of known diffuse densities. Averaging over 100 diodes, Dravins obtained a linear plot of log(signal corrected for dark signal and fixed pattern) versus log(illumination), up to saturation. The slope of the linear portion of this plot is not well determined, because the filters were used in a semi-specular manner, giving effective densities for the filters proportional to, not equal to, the diffuse densities. After measuring the filters in a photometer, Dravins concludes the slope is 1 "within experimental limits" but he does not bother to state those limits. He also investigated how the slope of the above plot changes as function of position in the array. He found variations to be "extremely small" and "at our measuring limit," but, once again, gives no numbers.

An attempt was also made to measure diode-to-diode sensitivity variations. The aim was to expose each diode to the same illumination level by moving them successively into the same position under a light source using a micrometer stage. The measurement was frustrated by scattered light on a 1% level (th quartz window had *not* been removed for Dravins' applicatication or this test), making the conclusions vague. It was estimated that any sensitivity variations across the array are 'slow," with

3 August 1976

an amplitude of 1 to 2 %.

(2) To conclude this section, consider an application of a RL512C described principally by Koppel.[16,17,18] The array used had a 1 μm thick SiO_2 passivation layer instead of the normal 3 μm layer. Operating the device at room temperature, with a clock rate of 100 kHz, the authors employed charge integration and sample-and-hold circuitry supplied by Reticon to process the signal induced by 1.8 to 2.3 keV photons. By subtracting off the combined dark signal and fixed pattern bias, and removing diode-to-diode sensitivity variations by multiplication with a set of calibration constants, they were able to obtain "intensity resolution of one part in 250."[18] Here, as elsewhere in the papers, the authors are sloppy and do not define what their terminology means but I think we can conclude that the best S/N ratio (mean signal level/rms noise on that signal for a given diode) they could reach was on the order of 250:1. Linearity of output to 8 keV photon radiation was tested. No details or numerical results are given, other than "within experimental accuracy" the output was a linear function of exposure from 10% to 95% of saturation level.

As a last note, the authors modeled the loss of spatial resolution due to diffusion of photon-induced carriers in the bul silicon for several X-ray energies. Undoubtedly the same equations would apply at lower photon energies, and would be helpful in a quantitative evaluation of interdiode "crosstalk."

23 August 1976

III. Summary and Further Discussion

In this section I bring together some isolated facts, thoughts, and such from various sources which I think are relevant in discussing the applicability of Reticon devices to our problem.

A. B Series

The B series devices represent an older design than the C, EC or F series. I have included them in this discussion mainly because I wanted to present the work that has been done with them (notably that at Kitt Peak). Edward Snow of Reticon feels that he would select a B series device over the others only if it were necessary to have the higher data rate obtainable with the older arrays. (private communication, 4 August 1976).

B. Quartz Window and Passivation Layer[19]

Normally, Reticon supplies its linear photodiode arrays with a 20 mil thick quartz window sealing the aperture in the array package. When ordering an array, one can ask to have the window omitted. The normal SiO_2 passivation layer thickness of 3 μm can be reduced to 1 μm, or, if necessary, it can be eliminated completely over the diodes themselves, leaving, however, a SiO_2 layer on the interdiode n-type silicon. From the experience of Livingston, et al, at Kitt Peak, it is clear we would want to eliminate the window to minimize the Fabry-Pérot fringing problem, but it is still not clear to me if it would be necessary or even helpful to change the passivation layer. This is one area requiring further thought and measurement as far as our application is concerned.

23 August 1976

C. Linearity

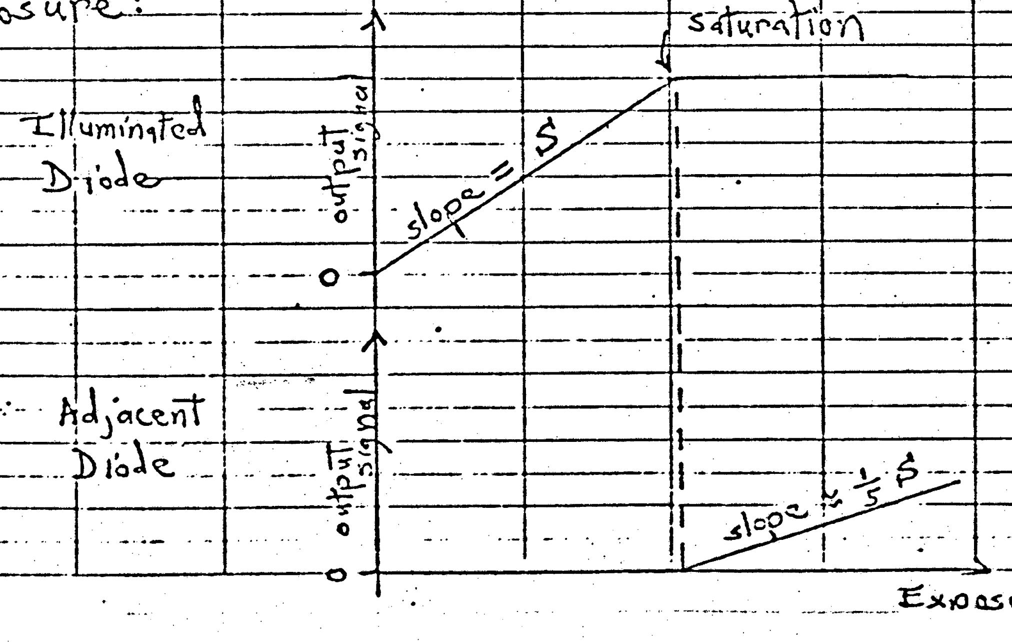
This is another area requiring work, as is clear from the results summarized above. The workers have attacked the problem from different points of view, with varying and often unstated degrees of accuracy, making useful inferences for our application impossible.

D. Crosstalk and Blooming

A telephone discussion with Edward Snow of Reticon (4 August 1976) yielded the following qualitative result, based on actual measurements attempted at Reticon (but hampered by scattered light problems). The discussion should give an indication of what should be generally expected for a Reticon linear photodiode array.

Suppose a light spot is limited to the photodiode of one photoelement (recall there are no sharp boundaries between photoelements; the n-type silicon between diodes is also photosensitive and contributes to the response of both adjacent diodes).

Below are the response of the illuminated diode and the approximate response of either adjacent diode, as a function of exposure:



Note exposure is confined to illuminated photodiode once the adjacent diodes have saturated, then the ones next to them can start "blooming," this time with slope $\approx \frac{1}{25} S$. The phenomenon then propagates out, extending the above process in the obvious manner.

E. Detection Circuitry

As I hope is obvious from the previous section, the performance obtained from Reticon photodiode arrays is highly dependent on the readout circuitry. I have not attempted a detailed discussion, because I lack the necessary background. It appears however, the two most thorough treatments are in the papers by Buss, et al, at Reticon[20] and Livingston, et al, at Kitt Peak[11], bearing in mind the obsolescence of the Kitt Peak electronics due to non-linearities.

I will, however, list a few fundamentals of circuit layout that have been stressed by Weckler.[21] He noted the necessity to totally decouple the +5 volt supply for logic from the +5 volt supply for array common. Two other lines which should be totally isolated are the analog circuit ground and the digital ground. He recommends placing clock drivers as near to the array as is feasible, and to build the circuits such that the amplifier input(s) is (are) symmetrically located with respect to the clocks. This helps prevent asymmetries between the signals appearing on the different video lines.

23 August 1976

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Note: the RL-936F apparently is not available commerciall at this time.

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23 August 1976

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