P20

Instantaneous Automatic Light Control for CMOS Imagers

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Some imaging applications with artificial lightening need exposure control that can utilize the present illumination during the exposure of the actual image. Utilization of previous picture(s) may be inaccurate at low frame rates, and pre-flashing of objects just prior to the actual exposure may be an unwanted waste of energy. The objective of the presented automatic exposure control function is to adjust exposure time and readout gain.

As the intensity can vary across an image. Therefore, monitoring active pixels rather than dedicated sensors or pixels outside the array is chosen. To achieve this, the pixels inside image array are read non-destructively during exposure. The outputs are sampled at a certain scanning rate and in each scan, compared to a reference V_{ref}. The block diagram in figure 1 shows the comparators and how they are connected to the pixel outputs (columns). In our case, the non-destructive reading is limited to a subset of pixels for faster scanning.

A criterion for correct exposure is a defined number of scanned pixels having reached a certain digital output level. The exposure time and gain are both set by an algorithm that finds the best combination. This algorithm will actively change the reference level dependent on the light intensity. Therefore, the reference voltage is generated dynamically using the Switched Capacitor circuit shown in figure 2.

In CMOS sensors, the signal V_{signal} presented to the ADC is the amplified difference between the pixel level V_{reset} after reset and the pixel level $V_{pix}(t)$ at t_{int}, the end of the integration period: $V_{signal}= [V_{reset} - V_{pix}(t_{int})]G$, where G is the gain. During the non-destructive readout the pixel outputs, $V_{pix}(t)$ is referred to ground and not amplified. Therefore, the reference input to the comparators V_{ref} must be derived from the pixel reset level, the actual readout gain, and the ADC input V_{lev}, which represents the desired digital output level: $V_{ref} = V_{reset} - V_{lev} / G$.

The algorithm sets the SC amplifier gain to the inverse of the readout gain. The mean reset level is added directly to the non-inverting input. The pixel reset level which is not available from the actual pixels, is obtained by sampling the analog average from dark dummy pixels at the top and bottom of the array, as shown in figure 3.

The ADC full scale is sampled from the ADC reference. The sampling capacitors C_r and C_{fs} keep the reset and ADC reference respectively. To reduce the leakage from the two sampling capacitors, outputs from the S/H amplifiers are applied to their respective terminals of the sampling switches opposite to the storage capacitors.

The accuracy is dependent on how well the reset level of the dummy pixels matches the real pixels, how well capacitors in figure 2 (inverted gain) matches the capacitors (gain) in the actual readout amplifier, and the time resolution given by the scan time. Trimming is added to improve the matching accuracy. To improve the time resolution, the number of pixels that have reached the reference is checked after each row in the sub array. Thus, the time resolution is given by the time needed to sample one row.

As a measure of inaccuracy, we use deviation of the automatically set exposure time from a manually set exposure time with correct number of pixels at correct level. The correct level itself and the number of pixels at that level are both dependent on the nature of the image. Therefore, the application must be taken into consideration when these parameters are chosen. The test image used during the characterization was a random pattern, a map of 40 by 40 squares. The squares are grey levels randomly distributed around a mean value and ranging from black to complete white. Prior to trimming, the accuracy and die to die spread is found to be within 5%, as shown in figure 4. The implemented trimming is done by varying the V_{lev}, which is derived from the ADC reference. These trim levels are controlled by internal registers via switches.

The behavior of the automatic light control is presented in figure 5. The light source is a set of white LEDs thought which the current was swept from 10mA to 2.2A in increments of 10mA. The sweep covers all gain settings and slightly exceeds the imager exposure range. Top graph shows that the pixel output mean value is constant over the LED current sweep while the lower graph shows how the exposure times varies to maintain stable output level. The steps in exposure time reflect change of gain.

To conclude: It is shown that a direct light measurement can be done in CMOS image sensors by repeated non-destructive reading of pixel during the exposure. Characterization of the imager shows that the ALC has no influence on Fixed Pattern Noise, photo response non-uniformity, or lag. The exposure accuracy without trimming is within 5%. With trimming, the accuracy is limited by the time resolution that is either the scan time of the pixel subset or if the exposure check is done after each row, the row time.

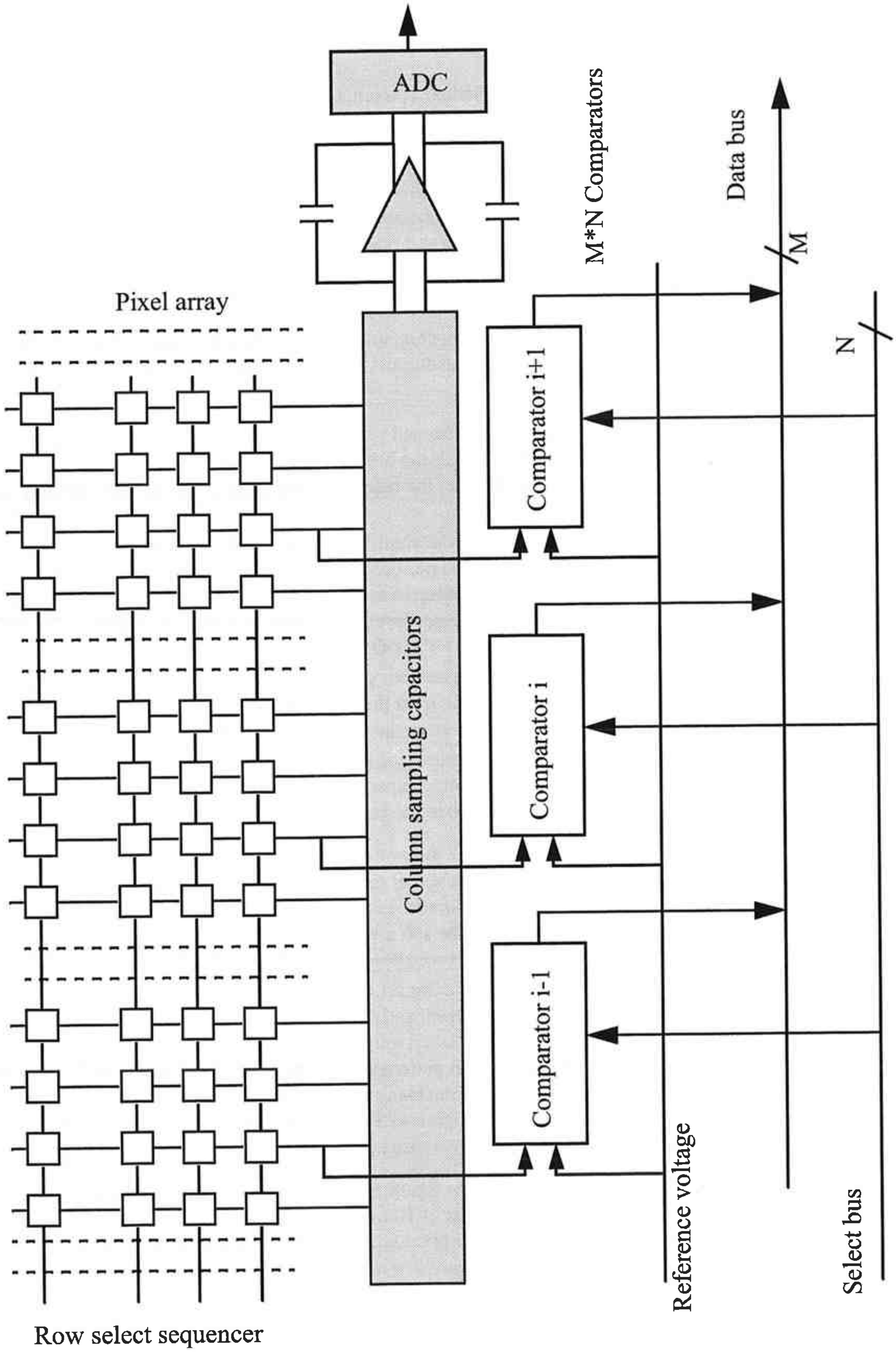

Figure 1: ALC block diagram.

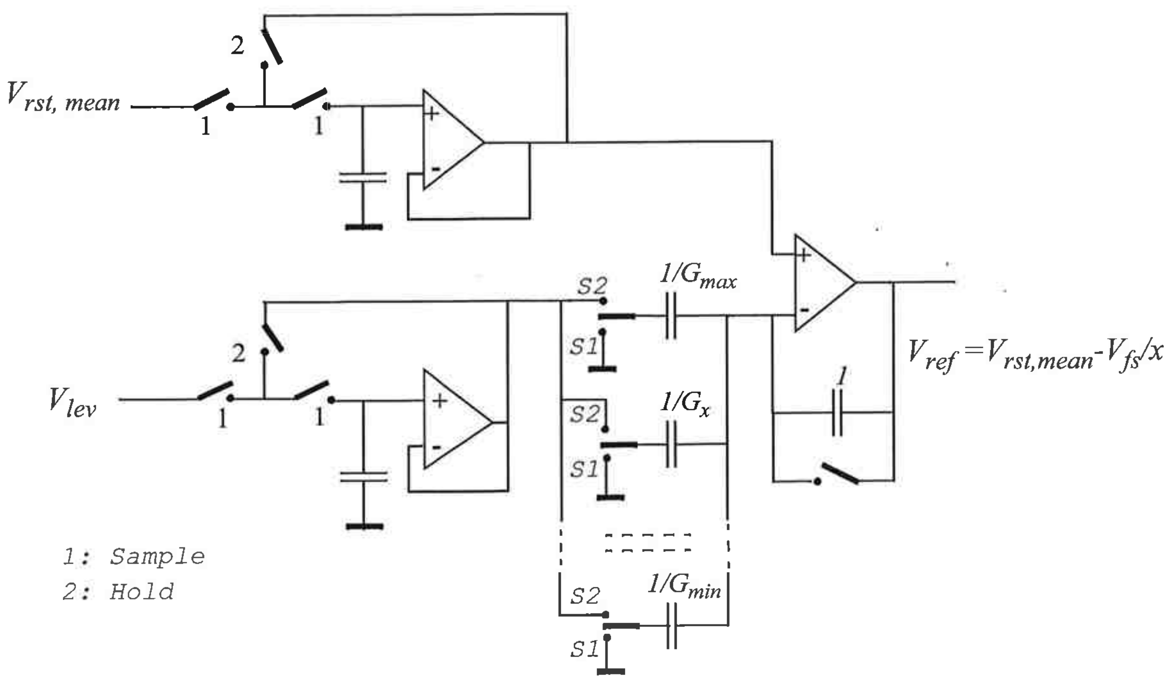

Figure 2: Level sampling and V_{ref} formation

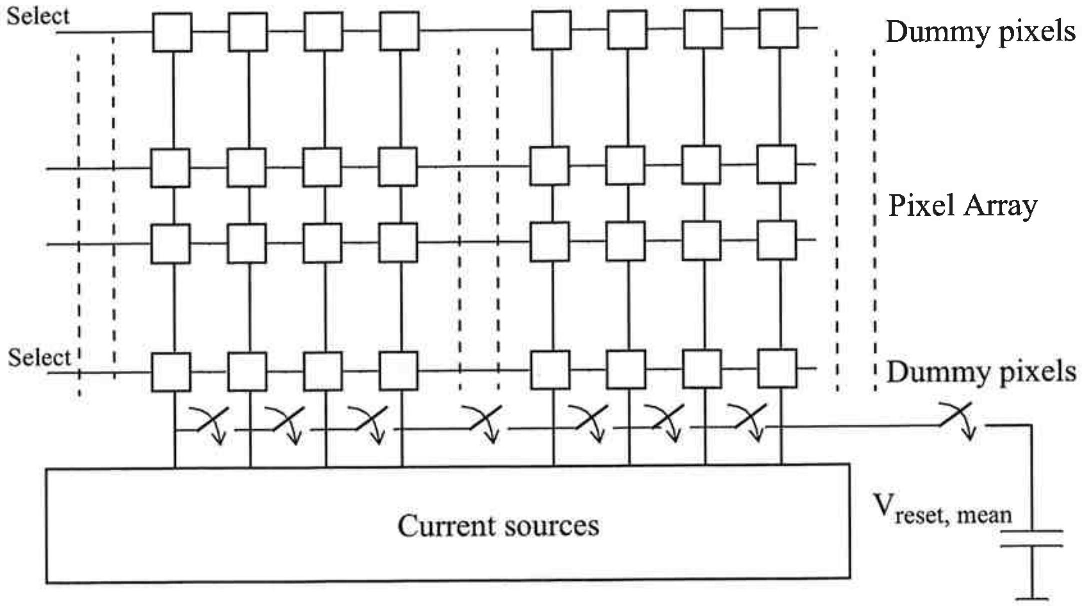

Figure 3: Analog formation of average reset level from dummy pixels

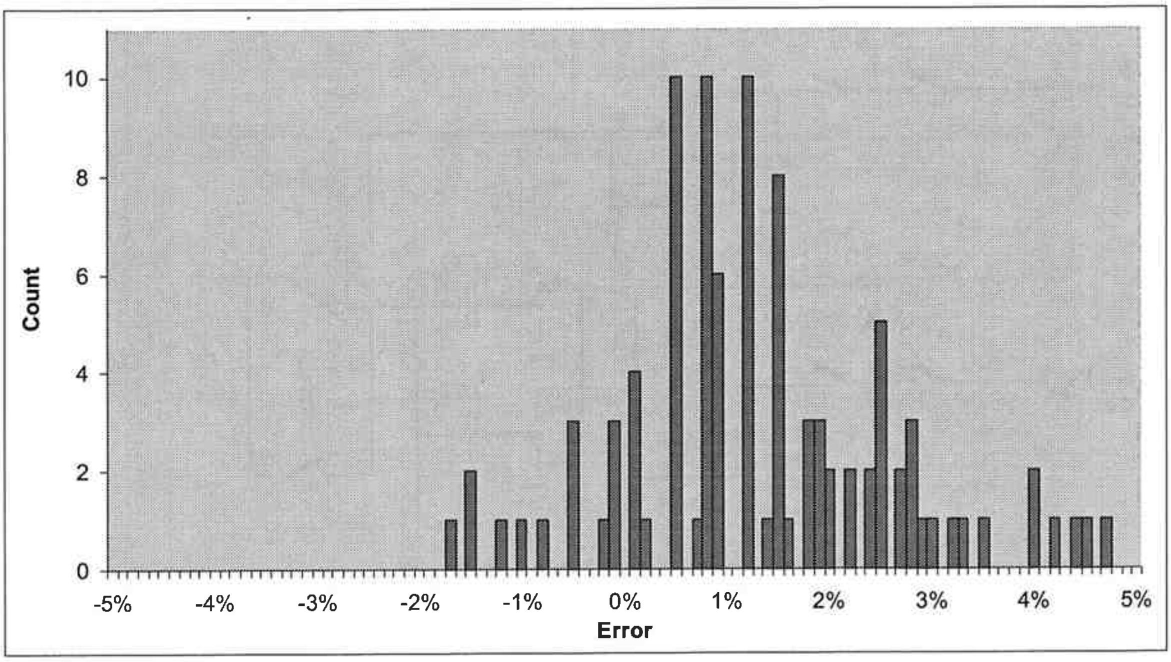

Figure 4: ALC Error distribution

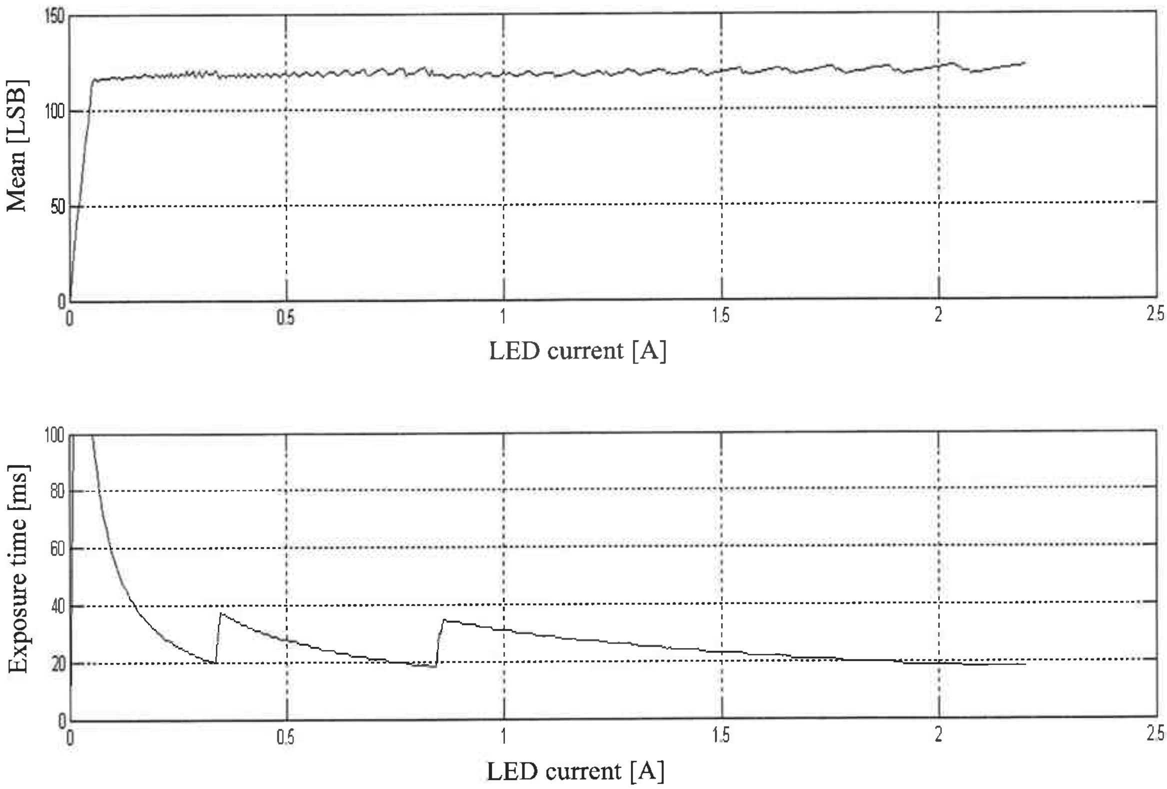

Figure 5: Output level as function of light intensity