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Review Article

NMOS Linear Image Sensors: A Review of Data Acquisition and Monitoring

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Abstract: This paper analyzes data acquisition and monitoring techniques used with negative-metal-oxide semiconductor (NMOS) linear image sensors. NMOS sensors have gained significant attention in various fields due to their advantages in terms of sensitivity, dynamic range, and low noise characteristics. Through a systematic review, the paper explores the fundamental characteristics of NMOS sensors, including their operation, sensitivity, and limitations. Data acquisition techniques will cover readout circuits, sensor resolution, timing characteristics and monitoring stratergies. A microcontroller can receive the gathered data and store it for later use

Keywords: NMOS, Acquisition and Monitoring.

1. Introduction

Linear image sensors based on Negative-Metal-OxideSemiconductor (NMOS) technology offer a potential alternative to conventional CMOS image sensors in specific applications. It is a specialized photodiode array that autonomously scans itself and is used in multichannel spectroscopy detectors. These are spectroradiometers which are commonly utilized in the field and laboratory settings to assess land surface reflectance factors and collect information about their properties. However, achieving accurate and comparable data poses significant challenges due to environmental influences and instrumental constraints[1]. When adhering to a standard fabrication process for the image sensor system, opting for NMOS technology reduces the component and packaging expenses, and notably, its capability to integrate multifunctional circiuitry on the same chip[2].

The sensor has several attributes, including a generous photosensitive region, high sensitivity to ultraviolet(UV) light, consistent performance even under UV exposure, a broad dynamic range[3] and minimal dark current. Unlike conventional real-time signal readout methods commonly used in photodiodes, the NMOS linear image sensor employs a distinct charge integration approach to extract signals. The signal output corresponds solely to the intensity of the incident light. Photons of light are detected and processed, converting generated charges into electrical energy, represented by voltages, as they are received sequentially using a horizontal shift register for each pixel[4]. The photodetector data can be utilized for many other things, like locating the sun's brightest point and serving as a reference for figuring out the amount of aerosol in the atmosphere[5]. A light-sensitive MOS (Metal-Oxide-Semiconductor) transistor is distinguished by its elevated optical gain and non-destructive readout functionality. The device operates on a principle where incident light alters the surface potential beneath the gate, consequently modulating the source current flowing within a buried channel based on this surface potential[6].

Use references to provide the most salient background rather than an exhaustive review. The last sentence should concisely state your purpose for carrying out the study or a summary of the results [2].

(Rest of the paper is organized as follows, Section 1 contains the introduction of NMOS Linear Image Sensors, Section 2 contain the structure of NMOS Image Sensors, Section 3 contain the overview Charge Intergration Method of NMOS Image Sensors, Section 4 contains the overview of Readout Method of NMOS Image sensors, section 5 contains the characteristics of the sensor , Section 6 contains the data of data acquisition, timing characteristics and its properties, Section 7 contains the method of data monitoring, Section 8 concludes research work with future directions).

2. Structure of NMOS Linear Image Sensor

The NMOS linear image sensor, illustrated in Figure 1, is composed of distinct components. These include a photosensitive segment containing a photodiode array, a switch section tasked with retrieving signals from the photodiode array, and a shift register responsible for managing and controlling these switches. The MOS phototransistor comprises an annular gate structure consisting an N + diffused source region internally and an N + drain region externally. The N-type channel is embedded in an N − epitaxial layer with a concentration of roughly 1013cm−3 [6]. The gate electrode’s immediate vicinity is the only area with light sensing capabilities, and the N+ drain region also serves as an optical isolation. The device’s fabrication technique is comparable to the CMOS fabrication process

NMOS sensors use a charge integration technique for signal extraction. These sensors usually have low energy consumption, a large photosensitive area, and increased sensitivity to ultraviolet (UV) light. On the other hand, CMOS sensors employ a real-time signal readout mechanism that correlates directly with incident light intensity and combine all required components onto a single chip.

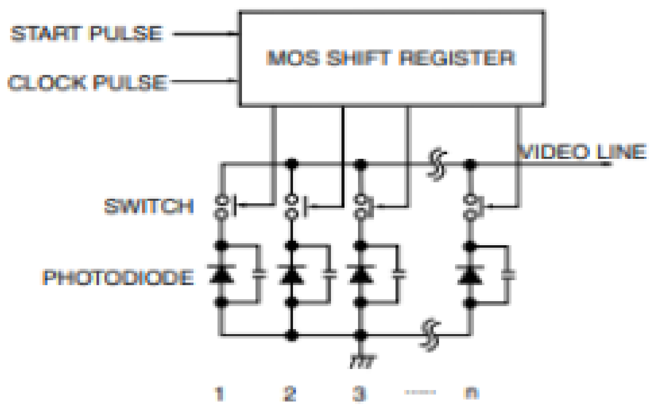

Figure 1. Equivalent circuit of NMOS image sensor[2]

3. Charge Integration Method

The charge integration method involves accumulating the generated electrical charges from incident light over a certain period of time. These charges are then converted into a measurable voltage signal, providing an indication of the light intensity captured by the sensor. This method entails gathering the electrical charges produced by incident light within a specific timeframe. Following this, the accumulated charges are transformed into a voltage signal, enabling measurement and indicating the detected light’s intensity by the sensor. The integration time of each photodiode represents the period between the activation of a specific switch for signal retrieval and the subsequent activation of the same switch for the next readout. This duration is equivalent to the time gap between consecutive start pulse signals for the MOS shift register. There may be any alterations in the incident light level during this integration time, such changes cannot be detected. Due to the sequential activation of switches for each photodiode during signal retrieval, the start time for integration undergoes slight shifts. Hence, variations in light levels over time result in non-constant signal outputs from individual photodiodes, even when the entire image sensor receives uniform illumination.

The anode of the nmos linear array is at 0 volts , so a positive bias is applied to the video line. This is achieved by providing the reset pulse with the amplitude same as that of the ϕ1, ϕ2 and ϕst signals [3]. The photon-electron conversion gets due to the current multiplication by avalanche process, were the noise is also multiplied. However, the amount of photo carriers depends on the incident photon on the elements. The charge integration involving photonelectron conversion is almost noise independent. At 77 K the efficiency of Si Avalanche Photodiode (APD) was 60%, and this efficiency needs to be increased for providing photon noise discrimination. In the absorption region of avalanche photo diode electron-hole pairs are generated which are proportional to the intensity of the light incident, then the photo-electron are being multiplied and amplified with a high gain and very low noise. These are then read out as voltage signals after current to voltage convertion inside the chip[7].

4. Readout Method

Each photodiode’s signal is sequentially transmitted via a single output line, eliminating the need for separate readout circuits for each photodiode. This simplifies the external circuit design. When a shift register receives an external start pulse concurrently with a two-phase clock pulse, it initiates a sequence that activates the address switch of the first channel’s photodiode, enabling the sequential reading of each photodiode’s stored signal. If a subsequent start pulse is applied before completing the readout of all channels, it leads to the simultaneous activation of multiple address switches, causing malfunction. Therefore, it’s necessary to ensure the interval between start pulses effectively the sensor’s integration time is longer than the total time needed to read through all channels. NMOS linear image sensors employ a readout technique distinct from that used with traditional photodiodes, necessitating a thorough understanding of these differences for adjusting the sensor settings appropriately, taking into account variables like the amount of incident light and the desired length of integration time[8]. In the process of reading data from image sensors, fixedpattern noise is typically reduced through the use of correlated double sampling (CDS). This method often employs current mirrors for current mode readout. However, the precision of these current mirrors can be compromised under conditions of low signal (such as low light) or because of channel length modulation effects. Compared to readouts that operate on voltage, those function in current mode are more likely to experience non-linear responses due to the degradation of carrier mobility. Furthermore, the necessity for current operations means that any additional paths for dc current must be carefully managed to ensure energy efficiency[3]. In a differential output waveform, the maximum value is used as the signal output. The waveform shape differs significantly between high and low outputs, with lower amplitude signals taking longer to reach their peak values. Consequently, the peak-to-area ratio of the differential waveform declines. This is because the waveform’s area represents the total charge to be read out.

5. Resolution and Field of View

The main functionality of a linear array is that, if we use a photodiode, the resolution drops because a photodiode only has one pixel, making it impossible to detect the circumference of the sun or any other light-emitting object[13]. Even a falling light item could fool the user by being mistaken for the sun. The circumsolar radiation of the sun reaching the earth surface shown in the Fig 2. When discussing the sun, the photosensor array can even identify dark areas in the sun, something that a standard one-element detector cannot do. The resolution of NMOS linear array photodetector depends upon the number of photodetectors in the array, and how it aligned in a row. Each photo-sensitive photodetector is a pixel and the number of pixels represents the resolution of the chip. The NMOS linear array photodetector has 128 elements, i.e. 128 pixels, and as the number of elements increases its resolution as well as its accuracy increase, but they also require more processing power and memory to manage the increased data. The capability of this array is that the whole object which radiates light is fully captured. The size of the object, consider a sun or a torch the whole area of the object is being captured in several photosensitive elements, say about 25 elements as an example and we can say that out of 128 elements, the object is radiated on 25 elements of the array. The size of the array depends on the object to be captured[17]. The size of the object disk captured depends on the control of the field of view[15]. The field of view of one pixel of linear array is 0.02° and so the field of view of 128 pixels will be 2.56°. If the angular diameter of the sun is 0.5° the sun's disc falls on 26.5 pixels of the linear array[12]

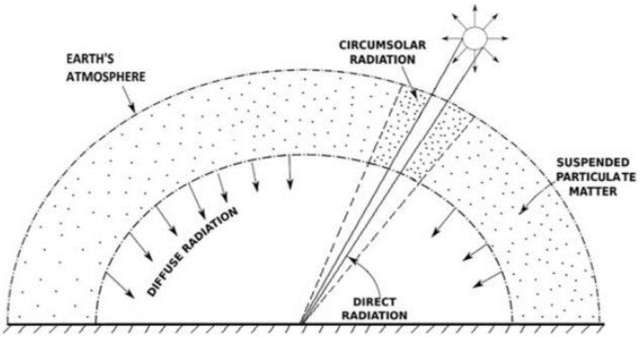

Figure 2.. Circumsolar Radiation of Sun

6. Data Acquisition and Timing Diagram

The signal output in a differential output waveform is the maximum value. However, the high and low outputs have quite different waveform shapes, with the lower amplitude signals taking longer to reach their peak values. As a result, the differential waveform's peak-to-area ratio decreases[18]. This is so because the area of the waveform indicates the entire charge that has to be read out. Therefore, the slope is steeper for low outputs compared to high outputs when evaluating input/output characteristics using the current-to-voltage conversion technique. Therefore, despite its restrictions, this signal readout approach offers quick readout times and simpler circuit designs, making it a good choice for low-level highprecision light detection.

6.1 Clock configuration

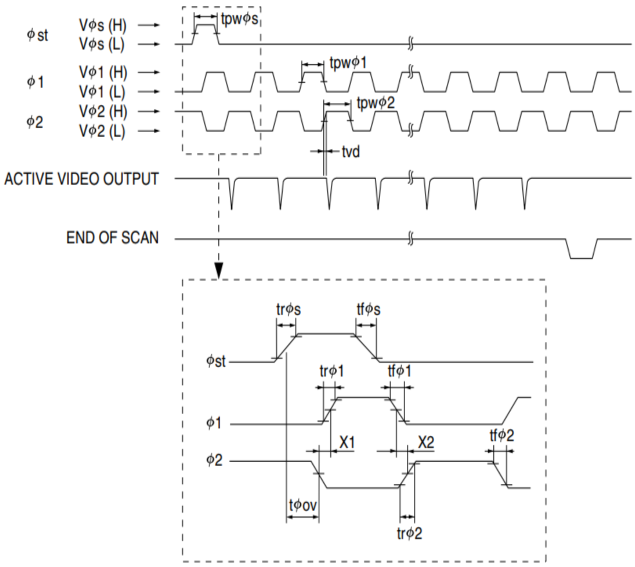

Figure 3. Timing diagram of NMOS linear image sensor[2]

Positive polarity is present in the two-phase clock pulses, Φ1 and Φ2, in Fig.3 which have a suggested amplitude voltage, VΦ, of 5 V, with a minimum of 4.5 V and a high of 10 V. The amplitude voltage, VΦst of the start pulse Φst which also has positive polarity, ought to coincide with the voltage of the clock pulse, VΦ The shift register can be driven without any DC voltage. For the video line, a positive bias voltage (Vb) is needed. In the current-to-voltage conversion or current integration method, this voltage is applied to the operational amplifier's non-inverting input terminal. V minus 3 V is the recommended voltage for Vb [3].

6.2. Timing Characteristics

The operation of two-phase clocks ϕ1 and ϕ2 is critical for timing-dependent processes, such as data readout in imaging sensors. They can operate independently or sequentially but cannot be simultaneously "high" ensuring synchronization and preventing conflicts. If the rise and fall times of ϕ1 and ϕ2 exceed 20 ns, additional clock space should be added to accommodate these delays, with clock space X1 and X2 longer than "rise time/fall - 20 ns" as necessary. A pulse width of at least 200 ns between ϕ1 and ϕ2 ensures stable recording. The start pulse ϕst, with a duration of at least 200 ns and an overlap of at least 200 ns with ϕ2, initiates the switching process, with ϕ2 transitioning from "high" to "low" once during the "high" phase of ϕst. Resetting the photodiode capacitance of the NMOS linear image sensor occurs during the read cycle when the address switch is activated, requiring ϕ2 pulse width synchronization with the address pulse to prevent hysteresis. While ϕ1 is mainly for scanning and can have a longer pulse width, in high-speed readout mode (1 MHz or higher), the duty ratio of ϕ1 and ϕ2 should be set to 1:1 for proper synchronization and efficient data transfer.

6.3. Signal Readout

After all elements in array get read out as current with an external integrator, there will be need of an additional reset pulse (ϕreset) to reset the integration capacitance, but the sharing ϕreset and ϕ1 is possible using a timing pulse as shown in Fig.3, without any degradation of pulse conditions. Considerations for the rise and fall of the ϕreset pulse are crucialy specifically, the rise of the ϕreset pulse must be separated from the fall of ϕ2 by at least 50 ns to ensure a consistent reset potential for the photodiode. In both the reset time and loading time for the photodiode potential, ϕ2 exceeds the width of ϕ1. However, if the ϕreset pulse is too short, incomplete resetting of the integrating capacitance can occur, potentially leading to issues. A delay may occur due to external circuit from these problems [3].

6.4. Data Transmission

In an NMOS linear array photodetector, data transmission typically involves converting the photo-generated charge into an electrical signal, which is then read out by the NMOS transistors in the array. Each photodetector element generates a charge proportional to the incident light intensity, which is then amplified and read out sequentially[16]. After all 128 elements of the array receive radiation and data collection concludes, an end-of-scan (EOS) pulse is generated immediately following the last pixel's readout. The photosensitive component features P-N junction photodiodes, with an N-type diffusion layer situated on a P-type silicon substrate. Serving as a photoelectric converter, this component transforms light signals into electrical signals and briefly stores the acquired signal charge. Pin Vss is connected to the anode (P-type silicon) of every photodiode. The photodiode is designed in such a way that it shows high sensitivity to UV rays and also provides low dark current. NMOS has an inverting property that affects the linear array photosensor [3], i.e. when a high-intensity light falls on the elements the output of the photodetector will be a high to low falling pulse which is a current signal that is being converted into a voltage pulse by an inbuilt trans-impedance amplifier in the chip. The NMOS transistors serve to amplify and multiplex the signals from the individual photodetector elements for further processing or transmission. The Active video out or the analog output voltage value from the array is serially given to a microcontroller which can convert it into a digital signal with an inbuilt analog-to-digital converter or an external ADC before the data enters the microcontroller. The data can be used for further purpose.

6.5. Noises

In NMOS linear array photodetectors, noise originates from various sources, impacting the device's performance and sensitivity. The level of these noises remains consistent under defined readout conditions, allowing them to be subtracted from each pixel during signal processing. On the other hand, random noise arises from inaccurate fluctuations in voltage, current, or electrical charge during the signal output process. This type of noise, occurring within the image sensor and readout circuit, sets the lower limit for light detection or the dynamic range when fixed pattern noise is subtracted externally[21].

Dark Current Noise arises from the flow of leakage current through the photodetector when there is no incident light, and its impact becomes more pronounced with higher temperatures or as the device ages. On the other hand, 1/f Noise, also known as flicker noise, manifests with a frequency dependence and can originate from different sources such as semiconductor imperfections or surface states. This type of noise places fundamental constraints on the performance of image sensors, particularly in scenarios with limited illumination[20]. Temporal noise in NMOS active pixel sensors arises from various sources, including photodetector shot noise, output amplifier thermal noise, and 1/f noise. It affects sensor performance, particularly in low-light conditions, alongside thermal and shot noise from pixel transistors and column amplifiers. Additionally, Readout Circuit Noise from amplifier and multiplexer imperfections further impacts signal quality. Overall, managing temporal noise is crucial for optimizing sensor sensitivity and image quality[19].

7. Data Monitoring

When considering data acquisition and monitoring for NMOS linear image sensors, various monitoring systems can be utilized, each tailored to specific requirements such as sensor size, location, purpose, and budget constraints. At the local level, monitoring systems are developed to collect and analyze data directly at the sensor's measurement location. The system operates independently of telecommunication networks, storing data locally on SD cards and requiring minimal upkeep. However, in cases where local monitoring alone may not suffice, remote monitoring systems become necessary. These systems enable data collection and analysis from a different location, often employing wired or wireless transmission technologies. In certain instances, data is processed locally before being transmitted to a remote monitoring center. For instance, processed collected data locally before recording it in a database for remote access and analysis[22]. In more advanced setups, centralized monitoring systems are utilized to oversee multiple NMOS linear image sensors deployed in a system. These centralized systems gather data from sensors and store it in a centralized database for comprehensive visualization and analysis[16].Most of the time, the information can be kept, used as scientific data, and investigated for more research.

8. Conclusion

In conclusion, this systematic review has provided valuable insights into the data acquisition and monitoring techniques employed in NMOS linear image sensors. Through a comprehensive analysis of existing literature, key findings have been highlighted, shedding light on the way a linear image sensor behaves in response to light exposure for effective data gathering and monitoring. The review underscores the significance of timing characteristics of image sensors and addressing temporal noise, photodetector shot noise, and other sources of noise in NMOS sensors to enhance their performance and reliability. Furthermore, the review emphasizes the importance of integrating effective monitoring systems to ensure accurate data acquisition and real-time monitoring capabilities. Moving forward, continued research and development efforts in this field will be essential for advancing the capabilities of NMOS linear image sensors and maximizing their potential across diverse applications like can be used for climatic studies by sensing the variations of sunlight in the sky. The same can be used in space missions or even underwater communication.

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