Abstract

Mother nature created life and blessed us with this beautiful world. Mankind always takes inspiration and resources from nature to train the brain and to do innovations for making the life easier. There are countless inventions that make this world a better and comfortable place to live in. With the evolution of technology, humans have begun to build artificial replicas similar to their own body.

Eyes, one of the most important senses of the human body, became the inspiration behind the invention of the camera. Eyes respond to the light information in a scene, extract and transfer it into the electrical signal and send the information to the brain for processing. Based on the working principle of eyes, a camera extracts the information from a scene, processes, stores, and reuses it. Being one of the finest inventions in the history of mankind, cameras found their applications in fields like entertainment, information, biomedical, geology, and space. In some critical applications, it becomes very important to extract and process the information from a scene with a fine accuracy and precision.

The performance parameters of a camera decide the quality of a picture taken from it. One of the very important parameters is the dynamic range (DR). The DR is a function of maximum and minimum perceivable input light by an image sensor or imager. The saturation level of the pixel sensor limits the maximum value of the input. The minimum detectable light depends on the pixel noise under the dark or low-illumination conditions. Therefore, to increase DR, it is important to reduce the noise of a pixel. In order to remove, it is critical to know and develop an understanding of all the sources of the noise
components associated with the circuitry of a camera.

Most of the modern age digital cameras are based on CMOS image sensors. Unfortunately, these image sensors show a poor noise performance compared to their counterpart, charge-coupled device (CCD) based image sensors.

With the growing technology, cameras became a system-on-a-chip, to achieve portability, lower cost, and lower power consumption. CMOS cameras are mostly embedded in battery-operated systems such as mobile phones, where power consumption is a major issue. Low-power budget and miniaturized circuitry, employed with components shrunk up to the nanometer range, severely hamper noise performance. The minimum detectable signal is limited by pixel offset and random noise, including the low-frequency noise of the in-pixel source follower (SF) and the thermal noise of the switches. In-pixel offset and thermal noise from the reset switch can be canceled by techniques like double sampling (DS) and thus, the source follower low-frequency noise remains as a major noise source to limit the dynamic range of an image sensor. In addition, the non-linearity of the SF also hampers the output of a pixel sensor.

The low-frequency noise includes phenomena like RTS, burst, and $1/f$ noise. Random trapping and de-trapping of mobile charge carriers, into the lattice defects, present at Si-SiO$_2$ interface of a MOS device in the form of unsaturated energy states or traps, are considered as a major cause of the low-frequency noise. Although many models have been proposed by many researchers, yet the exact origin of the $1/f$ noise is still unclear. The low-frequency noise model presented in this thesis is based on McWhorter’s carrier density
fluctuation ($\Delta N$), which considers that the $1/f$ noise originates from the number of mobile charge carrier fluctuation into the channel and its spectrum is the superposition of the RTS noise from multiple traps. In the explored mathematical model, the low-frequency noise power spectral density is derived for a MOSFET device under variable biasing conditions. The model considers the non-stationarity in the noise behavior due to time-varying biasing conditions, which is more suitable for the application such as CMOS image sensors. The theoretical modeling and analysis of the RTS and $1/f$ noise in MOS transistor show that the $1/f$ noise power can be reduced by decreasing the duty cycle ($D$) of switched biasing signal. In this thesis, an analysis of $1/f$ noise reduction model is presented, and it is shown that the RTS noise reduction is accompanied with a shift in the corner frequency ($f_c$) of the $1/f$ noise and the value of the shift is a function of continuous ON time ($T_{on}$) of the device. The reduction in $1/f$ noise is also shown experimentally. The circuit configuration with multiple identical transistor stages is used to produce a continuous output instead of a discrete signal. The measured results show that the proposed technique reduces the integrated $1/f$ noise power by approximately 5.9 dB at switching frequency ($f_s$) of 100 KHz for 2 stage configuration, which is extended up to 16 dB at $f_s$ of 5 MHz for 6 stage configuration.

The latter part of this thesis presents a low-noise CMOS image sensor prototype with enhanced dynamic range (DR) using a novel in-pixel chopping technique. The proposed in-pixel chopping technique is used to reduce the low-frequency or $1/f$ noise of the SF. A conventional 3T active pixel, with n-well/p-sub photodiode (PD), is modified to implement a chopper inside a pixel. A single minimum sized nMOS transistor is used in each pixel,
without any considerable compromise in the fill-factor (FF). The reduction in the temporal noise also results in an enhanced dynamic range of the image sensor. Moreover, the readout comprises a column level high gain chopper amplifier that also reduces the non-linearity of the source follower.

To validate the proposed technique, a prototype sensor has been fabricated in 350 nm standard CMOS technology, which consists of a 128×128 sized pixel array with in-pixel chopping and column level read-out circuitry. The temporal noise is measured as 280 $\mu V_{RMS}$ at the chopping frequency ($f_{ch}$) of 8 MHz, which shows a reduction in the integrated noise power by 11 dB. In addition, the column level high-gain amplifier makes the output follow the PD node linearly for a wider range of light integration, increasing the linearity and hence, the usable output swing. Due to the reduced noise floor, the dynamic range is enhanced from 65 dB to 76 dB, using the proposed technique.