UNIVERSITI PUTRA MALAYSIA

DESIGN OF STANDARD CMOS TIME-OF-FLIGHT PIXEL USING CHARGE TRANSFER EFFICIENCY METHOD

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By

AMAD UD DIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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Do they say: 'He has invented this Book himself?' Say: 'If that is so, bring ten surahs the like of it of your composition, and call upon all (the deities or gods) you can other than Allah to your help. Do so if you are truthful **(Surah Houd, Ayat # 13)**

I dedicate this humble effort, the fruit of my thoughts & study to my Parents (Dr Zahoor & Nusrat), Spouse (Nuzhat), my Sisters (Iram, Sadaf & Iqra), my Son (Hapi Bai), my teachers and to all those who love me for their support and encouragement they provided me to achieve this goal.

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

DESIGN OF STANDARD CMOS TIME-OF-FLIGHT PIXEL USING CHARGE TRANSFER EFFICIENCY METHOD

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April 2011

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Time of Flight (TOF) range imaging is performed by sensing the delay time, T_D of a known modulated light signal to reach the sensor after it has been back reflected from objects in a scene. This delay time is then used to measure distance of objects in a scene in real time. Recently, research on TOF image sensors has been receiving a great deal of attention mainly due to demand from scientific, medicine and industrial community. A CMOS TOF Pixels using the Gates on Field Oxide Structure has been realized where delay time dependant charge separation is achieved using two polysilicon gates that connect the photo collection site to two floating diffusion output nodes. The two outputs are consequently used to calculate the range of objects in a scene in real time. However, an extra mask layer is required to form a lightly doped n-buried layer under the gates and photo collection site to allow efficient charge transfer. Addition of this layer into the fabrication process increases cost. A solution to this is to design the pixel using standard CMOS circuit components.

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This thesis discusses the design of an Active Pixel TOF Sensor using high gain amplifiers to mimic the delay dependent signal charge separation mechanism as in the Gates on Field Oxide pixel. It focuses on amplifier selection based on its Charge Transfer Efficiency (CTE) which is defined as the ability of an amplifier to transfer charge from its input node to its output. Linearity of the TOF active pixel sensor depends on the CTE. Keeping in view the requirement of very high gain, four different types of amplifiers which are the Two-Stage OPAMP, Folded Cascode, Telescopic and Cascode amplifiers are designed using a 0.18μm CMOS process and analysed. From the analysis, it is concluded that the Cascode amplifier is best suited to be used in the TOF pixel as it has the highest gain of 131.21dB. This high gain gives a CTE of 95% while dissipating only1.32μW of power. The simulation concludes that a TOF pixel with a high CTE can be fabricated using an unmodified standard CMOS process, hence further reducing fabrication cost of these sensors.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

REKAAN PIKSEL CMOS MASA-TERBANG MENGGUNAKAN KEBERKESANAN PEMINDAHAN CAS

Oleh

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Jarak pengimejan masa penerbangan (TOF) di persembahkan dengan mengesan masa tertangguh, T_D daripada isyarat cahaya termodulisasi yang diketahui untuk sampai kepada pengesan selepas ianya di pantulkan semula daripada objek-objek dalam suatu scene. Masa tertangguh ini kemudiannya digunakan untuk megukur jarak objek-objek dalam suatu scene dalam waktu sebenar. Baru-baru ini, kajian ke atas pengesan imej TOF telah menerima banyak perhatian terutamanya kerana permintaan daripada komuniti ilmiah, perubatan dan perindustrian. CMOS TOF Pixel menggunakan gate pada struktur medan oksida telah direalisasikan di mana cas pemisahan bergantung kepada masa tertangguh dicapai menggunakan dua gate polisilikon yang menyambungkan tapak pengumpulan/pertukaran foto kepada dua nod keluaran floating diffusion. Kedua-dua keluaran kemudiannya digunakan untuk mengira jarak objek-objek dalam suatu adegan dalam masa sebenar. Namun, lebihan mask layer diperlukan untuk membentuk lapisan tertanam-n yang dimasukkan secara ringan dibawah gerbang dan tapak pengumpulan foto untuk membenarkan peralihan

cas yang lebih berkesan. Penambahan pada lapisan ini ke dalam proses fabrikasi menambahkan kos. Penyelesaian kepada perkara ini adalah dengan merekabentuk pixel menggunakan piawaian komponen-komponen litar CMOS.

Thesis ini membincangkan rekabentuk pengesan Pixel Aktif TOF menggunakan penguat gandaan operasi yang tinggi untuk meniru mekanisma caj pemisahan bergantung kepada TOF seperti di dalam gerbang pada pixel medan oksida. Ia memfokuskan kepada pemilihan penguat operasi bergantung kepada keberkesanan peralihan cas (CTE) yang di definasikan sebagai keupayaan penguat operasi untuk mengalihkan cas daripada nod masukan kepada keluarannya. Linear pixel aktif TOF bergantung kepada CTE. Mengambil kira permintaan terhadap gain yang tinggi, empat jenis penguat operasi yang berbeza iaitu OPAMP dua tahap, Folded Cascode, Telescopic dan penguat operasi Cascode direkabentuk menggunakan proses CMOS 0.18µm dan kemudiannya dianalisa. Daripada analisis, boleh dikatakan penguat operasi cascade paling sesuai untuk digunakan didalam pixel TOF kerana ia mempunyai kedapatan yang tertinggi iaitu pada 131.21 dB. Kedapatan yang tinggi ini memberi CTE pada 95% sementara menghilangkan hanya 1.32 µW kuasa. Simulasi mendapati pixel TOF dengan CTE yang tinggi boleh difabrikasi menggunakan proses standard CMOS yang tidak diubahsuai, seterusnya menggurangkan kos fabrikasi pengesan-pengesan ini.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or other institutions.

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