Faculty of Engineering

SOFT ERROR ANALYSIS ON DIGITAL CIRCUIT

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Grade: ____________

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Final Year Project Report √

Masters ☐

PhD ☐

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SOFT ERROR ANALYSIS ON DIGITAL CIRCUIT

Soft Error Analysis On Digital Circuit

NUR FA'IQAH BINTI SABTU

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering
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ABSTRACT

Soft errors, also known as Single Event Upsets (SEUs), occur due to the impact of energetic particles originating from sources such as cosmic rays, radioactive decay, or particle strikes. These incidents result in radiation strikes that can disrupt the charge in a memory cell, flip-flop, or register, leading to a flip or reversal of the data state. This study focuses on analysing the occurrence of soft errors in digital circuits. To investigate this phenomenon, an 8-bit Kogge-Stone adder circuit was constructed using VHDL code in Quartus II as part of this project. Additionally, a memory latch configuration known as C-element was designed to assess the impact of soft errors on the memory component within the adder system. Moreover, the goal was to find effective mitigation techniques that address soft errors without affecting the overall reliability of the circuit. For this particular project, one method that was implemented involved error detection and correction. Throughout the project, the system was able to successfully identify and mitigate the soft errors, ensuring the integrity of the data and the proper functioning of the adder system.

ABSTRAK

Kesalahan lembut, juga dikenali sebagai Gangguan Peristiwa Tunggal (SEU), berlaku disebabkan oleh tindakan partikel bertenaga yang berasal daripada sumber seperti sinar kosmik, peluruhan radioaktif, atau pemukulan partikel. Kejadian ini menyebabkan pemukulan sinaran yang boleh mengganggu cas dalam sel ingatan, flip-flop, atau pendaftaran, menyebabkan keadaan data terbali. Kajian ini memberi tumpuan kepada menganalisis kejadian kesalahan lembut dalam litar digital. Untuk menyiasat fenomena ini, litar tambah 8-bit jenis Kogge-Stone telah dibina menggunakan kod VHDL dalam Quartus II sebagai sebahagian daripada projek ini. Selain itu, satu konfigurasi pengunci ingatan yang dikenali sebagai elemen C telah direka untuk menilai kesan kesalahan lembut ke atas komponen ingatan dalam sistem tambah ini. Selanjutnya, matlamat adalah untuk mencari teknik mitigasi yang berkesan untuk menangani kesalahan lembut tanpa menjejaskan kebolehpercayaan keseluruhan litar. Untuk projek ini, satu kaedah yang dilaksanakan melibatkan pengesanan dan pembetulan ralat. Sepanjang projek, sistem berjaya mengenal pasti dan mengurangkan kesalahan lembut, memastikan integriti data dan fungsi yang betul bagi sistem tambah ini.

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LIST OF ABBREVIATIONS

BPSG	Borophosphosilicate Glass
CD	Completion Detector
CMOS	Complementary Metal-Oxide Semiconductor
CPU	Central Processing Unit
DRAM	Dynamic Random-Access Memory
FIB	Fault Injection Board
FIT	Failure in Time
FPGAS	Field-Programmable Gate Arrays
IC	Integrating Circuit
LET	Linear Energy Transfer
MBU	Multi Bit Upset
MCU	Multi-cell Upsets
PKA	Primary Knock Atom
RAM	Random Access Memory
RHBD	Radiation Hardening by Design
SBU	Single Bit Upset
SEFI	Single Event Interrupt
SER	Soft Error Rate
SEU	Single Event Upsets
SFI	Statistical Fault Injection
SIL	Single-inverter Latch
SOI	Silicon on Insulator
SoPC	System on Programmable

SRAM	Static Random-Access Memory
VTC	Voltage Transfer Curve

CHAPTER 1

INTRODUCTION

1.1 Introduction

In this chapter, overview of this project will be explained briefly. Therefore, the problem statement and the objectives are stated to provide some description regarding the project that will be conducted which is Soft Error Analysis on Digital Circuit.

1.2 Background

One of the major dependability problems with modern electronics is soft errors. Soft errors, also referred to as transient defects and unpredictable hardware issues. Soft error arises when there is a radiation strike that affect a charge disruption large enough to flip or reverse the data state of a memory cell, flip-flop and register. These inaccuracies were induced by alpha particles, which were present in the materials of the packaging in minuscule levels (a few parts per million) and were emitted during the radioactive uranium and thorium decay. The term "soft errors" was originally used to describe electronic device disruptions brought on by radiation at sea level [1]. To add, data that is transferring or has been stored may change when exposed to an eternal event such as an energy particle striking the chip [2]. Then, rather than the more typical single bit upset (SBU), more than one bit may be affected if the radiation induced has a greater energy, leading to a multibit upset (MBU).

Soft error known as Single Event Upsets (SEUs). SEUs is caused by energetic particles from cosmic rays, radioactive decay or particle strike. Striking of a particle becomes considerably more likely to result in an error as the elements size gets smaller since the amount of charge per device gets smaller because they are far more common and have lower energies where low energy particles can produce enough charge to result in a soft error [3]. The error rate brought on by SEUs, which varies on both the circuit characteristics and particle flow, is known as the soft error rate (SER) for a device. The amount of stored charge, the exposed cross-sectional area and also the charge collecting efficiency are device of circuit factors that influence the rate of error [3].

The flipping of a bit in the crucial system control register, like as one discovered in field-programmable gate arrays (FPGAs) or the control circuitry for dynamic random-access memory (DRAM), affect the product to malfunction. This is another situation of soft error which is known as a single event interrupt (SEFI), is different from typical memory soft errors in that each SEFI results in a direct malfunction, whereas typical soft error in memory either impact or not impact on the functionality of the final product, it still depending on the algorithm, sensitivity of data and other consideration [4].

Circuit dependability is becoming a serious problem in the deep sub-micrometer CMOS (Complementary metal-oxide semiconductor) technology nodes. The reliability degradation of digital circuits will cause some factors such as crosstalk, voltage drop, radiation-induced transient malfunctions [5]. But due to Moore's Law, technology scaling is advancing today to improve transistor performance, such as the frequency is increasing, transistor integration capacity is increasing to realise complex architecture and the amount of energy required for each logic operation is decreasing to keep power dissipation within the acceptable range. In addition, transistors are getting smaller and faster as fabrication technology improves, but the consequences will make the digital designs are more vulnerable to malfunction. Moreover, devices using the most recent CMOS technology, such as submicron and nano CMOS devices perform well in terms of high capacity, quick speed, and low power consumption will tends to be more susceptive to soft error as the feature sizes get smaller. In contrast, the soft errors are likely contributed to overall device failure due to an energetic particle generation as the size of technology reduced.

1.3 Problem Statement

Modern commercial electronic systems and components now face a significant risk from radiation-induced soft errors, which have the potential to surpass all other dependability mechanisms combined in terms of failure rates. Addressing this issue is crucial for designing computer systems, as the growing number of transistors can lead to higher defect rates per chip if appropriate measures are not taken. Microprocessor architects need to understand the impact of soft errors on their designs and choose effective approaches to minimize this impact while maintaining reliability. The scientific community can play a key role by developing better conceptual benchmarks, analysis techniques, and software tools to enhance our understanding and quantitative analysis of how soft errors affect system behaviour. Expanding and characterizing the range of soft error prevention, detection, and recovery methods is also essential to meet diverse reliability targets within practical constraints.

In today's context, soft errors have become a significant concern, particularly for state holders, and multiple bit upsets (MBUs) have gained importance in addition to single bit errors. Research based on [4] indicates that high-intensity radiation incidents can lead to MBUs rather than the more common single bit upsets. MBUs have an impact on memory architectures in error-correcting systems, even though they typically constitute a small percentage of the overall observed rate of single event upsets (SEUs).

It is possible to mitigate these particle-induced soft errors through appropriate detection and correction systems without compromising the overall dependability of an electronic system. Therefore, understanding the processes behind soft errors, determining their rates, and developing efficient mitigation strategies are critical. This project aims to analyse the impact of soft errors in digital circuits by simulating waveform data, providing valuable insights into this phenomenon.

1.4 Objectives

Below are the objectives for this project:

i. To design a digital circuit with injection of soft error by using Quartus II Altera Software.

ii. To analyse the waveform of the system in order to determine the effect of the soft error toward the adder system.

iii. To mitigate the soft error by applying error detection and correction method.

1.5 Scope of project

By considering both problem statement and objectives of this project, the scope of the research is to understand the concept of the soft error in digital circuit by implementing logic gates in circuit design and analyse the existence of soft error in the system of digital.

1.6 Structure of report

For final year project, the report features a proposed work and any relation of research toward the soft error analysis on digital system. This report consists of five chapters which are introduction, literature review, methodology, result, discussion and conclusion. The report outlines for each chapter shown below.

- **Chapter 1** represent introduction part. In this part, the overview of this project of "Soft error Analysis on Digital Circuit" was explained. The problem statement also stated in order to state the problem associated the soft error trend nowadays. Also, the objectives have been listed to achieve the project outcome by the end of the project. Furthermore, outlines of this report were provided too to deliver the content of each chapter briefly.

- **Chapter 2** of this report is literature review. This chapter present the research on many aspects of project that related to soft error and digital design too. Therefore, this part concludes the different perspective among researchers about the related title to provide better understanding to the readers.

- **Chapter 3** is the methodology. This section will provide the proposed method that will be used in this project through the research process. Flow chart of project's development also included in this part. Quartus II Altera software will be used for this project to create and design the digital circuit. The processes to construct some components and circuit with the mitigation of soft error on the system also presented under this chapter.

- **Chapter 4** present the waveform of the circuit and the analysis for each result. The analysis of the part emphasizes on the analysing circuits.

- **Chapter 5** is the part where the project will be concluded.

1.7 Summary of the chapter

This chapter which is chapter 1 has presented the overview and background of the project, problem statement, project objectives and the structure of report. According to research conducted by many researchers, they had proposed some concepts of framework to analyse better on the behaviour of soft error in order to implement some methods to mitigate soft error or SEU due to striking particle and to analyse the vulnerability of soft error rate in circuit design to increase the robustness of the system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section focuses on the topic of soft errors and their impact on digital circuits and systems, aiming to enhance the understanding of this project. Furthermore, relevant research on soft errors is presented in this chapter to provide insights and inspiration for conducting the project. Additionally, key concepts related to digital systems will be discussed to delve deeper into the analysis of soft errors in digital designs.

2.2 Soft error

Soft errors, also known as transient errors, are sometimes brought on by radiation like solar flares or cosmic rays in electrical devices. These errors can stop electronic systems from operating normally, which may destroy data or result in system failure. For sensitive systems, including those used in the aviation, healthcare, and financial services industries, soft errors can be challenging to identify and diagnose and have detrimental effects. These errors are sporadic and have nothing to do with enduring hardware issues [1]. As a result, energetic ions impacting the integrated circuit's sensitive volume cause charge production and accumulation, which is where the soft errors emerge [6].

Smaller cell geometries have increased the issue of neutron-induced soft error [7]. The author [8] also stated that soft error is a serious issue for stateholders because it can temporarily cause a circuit to malfunction, as they demonstrated in their experiment on the susceptibility of two types of C-elements to soft error. Engineers in the electrical, aeronautical, nuclear, and radiation fields have been studying soft errors for more than fifty years [1]. As a result, during the 1970s and early 1980s, researchers concentrated more on the physics behind these phenomena and gave radiation effects more consideration.

When space-borne electronics failed in 1975, the initial reports of faults attributed to cosmic rays were made at a time when there was little magnetic activity, making it improbable that the failures were caused by spacecraft charging. Through the author's study, a similar issue was discovered in dynamic memories at the subatomic level [9]. For instance, bits' values had fluctuated at random after the memory had been written. Even though the memory was undamaged, the identical data had to be stored twice before it could later emerge in a new place. It has been established that this phenomenon's non-permanent, irregular nature is why it was given the name soft error. Solutions with the capacity for error detection and repair are currently available on the market as a defence against soft error.

The design of the system, the materials utilised in its construction, and the operating environment are only a few of the variables that might significantly raise the vulnerability of electronic systems to soft errors. For instance, the increased flux of particles may make soft errors more likely in systems that operate at high altitudes or in regions with high cosmic radiation levels. Different methods and strategies, such as shielding, redundant design, and error-correcting codes, have been created to reduce the consequences of soft errors. These methods may be successful in lowering the frequency and impact of soft errors, but they may also make the system more complex and expensive. Overall, soft error continues to be a substantial problem in the design and operation of electronic systems, especially in mission-critical applications like aviation, defence, and space systems. Ongoing studies in this field are aimed at enhancing the robustness and dependability of electronic systems against soft errors.

2.2.1 Radiation Sources Lead Soft Error

Radiation sources are process that can lead to soft errors in electronic devices. Also, radiation can come from variety of sources, including the cosmic rays, solar radiation and radioactive decay. Generally, it occurs when ionizing radiation interacts with the atoms in material. Undoubtedly, these charged particles can cause soft error and lead to malfunction on the system itself. Therefore, for instance, it can cause the spacecraft to lose control or medical device deliver incorrect doses of medication. Clearly, those mechanisms of radiation need more further study to design the electronic devices that are resistant to them.