LIGHT-EMITTING DIODE DRIVER FOR LIGHTING APPLICATION USING FIELD PROGRAMMABLE GATE ARRAY

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DEDICATION

To my beloved

Nazarudin Mat Suah, Rosidah Mohd Noor,

Nur Liana Khusnan, Zayd Rizqi Muhammad Syazani,

Khusnan Khusni, Noriah Manap

and

Azli Yahya (Assoc. Prof. Dr.)

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ABSTRACT

Light-emitting diode (LED) is the most popular lighting source since the early 21st century. Its advantages include high efficiency, long lifetime and environmental friendliness makes it attractive in lighting application. This leads to the development of high energy efficient LED drivers. Despite the advantages, driving LEDs at high output ripple and without current regulation can degrade LEDs' performance. Furthermore, energy consumption of the controller on LED driver contributes to energy loss. Moreover, prototyping a full custom application specific integrated circuit (ASIC) is time consuming and not reprogrammable. The main objective of this research is to design an LED driver for lighting application using field programmable gate array (FPGA), and to analyse the performance. Simulation model was developed and simulated in LTSpice IV software. The LED driver controller was developed using Altera DE0-Nano FPGA Board with Quartus II software using Verilog hardware description language. The power stage schematic and printed circuit board layout were designed using Cadsoft EAGLE software. The LED driver performance was assessed in term of energy efficiency and output ripple. In energy efficiency experiment, rheostat was used as load. The result shows that the simulation model and the hardware prototype achieved energy efficiency of 93.36% and 93.19% respectively. In output ripple experiment, the result shows that the maximum output ripple of the simulation model is 0.046% while the hardware prototype is 0.06%. High-brightness white LEDs was also used as load in assessing the LED driver energy efficiency. The result shows that the hardware prototype achieved energy efficiency of 93.18% and has a maximum output ripple of 0.054% when high-brightness white LEDs are used as load.

ABSTRAK

Diod pemancar cahaya (LED) adalah sumber pencahayaan yang popular sejak awal abad ke-21. Kelebihannya yang mempunyai kecekapan tenaga yang tinggi, jangka hayat yang panjang dan mesra alam sekitar menjadikan ia begitu menarik dalam aplikasi pencahayaan. Ia telah membawa kepada pembangunan pemacu LED yang lebih cekap tenaga. Walaupun dengan kelebihan itu, pemacuan LED pada riak keluaran yang tinggi dan tanpa pengatur arus boleh merendahkan prestasi LED. Selain itu, penggunaan tenaga pada pengawal pemacu LED menyumbang kepada kehilangan tenaga. Disamping itu, proses memprototaip litar bersepadu aplikasi khusus (ASIC) memakan masa dan tidak boleh diprogramkan semula. Objektif utama penyelidikan ini adalah untuk merekabentuk pemacu LED untuk aplikasi pencahayaan menggunakan *Field Programmable Gate Array* (FPGA) dan untuk menganalisis prestasinya. Model simulasi dibangunkan dan disimulasikan dalam perisian LTSpice IV. Pengawal pemacu LED telah dibangunkan menggunakan Altera DE0-Nano FPGA Board dengan perisian Quartus II menggunakan *Verilog Hardware Description Language* (HDL). Skematik litar kuasa dan susun atur papan litar bercetak telah direkabentuk menggunakan perisian Cadsoft EAGLE. Prestasi pemacu LED dinilai berdasarkan prestasi kecekapan tenaga dan riak keluaran. Dalam eksperimen kecekapan tenaga, reostat digunakan sebagai beban. Model simulasi dan prototaip masing-masing mencapai kecekapan tenaga sebanyak 93.36% dan 93.19%. Dalam eksperimen riak keluaran, hasil menunjukkan riak keluaran maksimum bagi model simulasi adalah sebanyak 0.046% sementara prototaip adalah sebanyak 0.06%. LED putih berkecerahan tinggi juga digunakan sebagai beban untuk menilai kecekapan tenaga pemacu LED. Hasil menunjukkan prototaip telah mencapai kecekapan tenaga sebanyak 93.18% dan mempunyai riak keluaran maksimum sebanyak 0.054% apabila LED putih berkecerahan tinggi digunakan sebagai beban.

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LIST OF ABBREVIATION

FPGA	–	Field Programmable Gate Array
ASIC	–	Application Specific Integrated Circuit
LED	–	Light Emitting Diode
SSL	–	Solid State Lighting
PCB	–	Printed Circuit Board
PWM	–	Pulse Width Modulation
RTL	–	Register Transfer Logic
GPIO	–	General-Purpose Input Output
DC	–	Direct Current
SMPS	–	Switch-Mode Power Supply
SPICE	–	Simulation Program with Integrated Circuit Emphasis
MOSFET	–	Metal–Oxide–Semiconductor Field-Effect Transistor

LIST OF SYMBOLS

V	–	Voltage
A	–	Ampere
μ	–	Micro, 1×10^{-6}
m	–	Mili, 1×10^{-2}
k	–	Kilo, 1×10^{3}
M	–	Mega, 1×10^{6}
ε	–	Efficiency
%	–	Percent
Hz	–	Hertz

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Light-emitting diode (LED) is the most attractive in lighting application in early 21st century due to its advantages of high efficiency in term of light output and energy, long life time and environmental friendly. It has led to the development of improved light output high-brightness white LED, energy efficient LED driver, enhanced security and safety surveillance and development of Li-Fi (High-speed and fully networked wireless communication technology using LED light) [1]. The researches in LED driver efficiency becoming more important as the world is moving toward adopting renewable energy. Thus, the main objective of this research is to develop a high energy efficient LED driver using field programmable gate array (FPGA) as LED driver controller. By enhancing the energy efficiency of LED driver, this research is in line with Energy Commission act 2001 and Electricity Supply Act 1990 by Malaysian government which to promote the efficient use of electricity [2-4].

1.2 Overview of LED History and Development

In 1907, Captain Henry Joseph Round conducted an experiment by flowing electric current through a carbide crystal. The carbide crystal was emitting yellowish light, which mark as the first recorded observation of electroluminescence phenomenon [5]. However, the yellowish light emitted was not good enough for practical use [6]. Nick Holonyak invented a red LED, which he later coined as ‘Father of the LED’. The red LED's invented by Holonyak were too dim to be seen in daylight. It was mainly used as indicator lights for various application. A former graduate student of Holonyak, George Craford invented the first yellow LED and brighter red LED than Holonyak’s red LED in 1972 [7].

High-efficiency LEDs for fibre optic telecommunications was invented by T. P. Pearsall for fibre optic telecommunications in 1976. To achieve high-efficient LED, Pearsall designed new semiconductor materials that specifically adjusted to fibre optic transmission wavelengths [8]. The new colours became available as technology advanced in the 1970's. The demand of LED grew as the new uses of LED light discovered [9].

The semiconductor materials used in LEDs are further refined in 1980’s. In the 1980's, the first super bright LED's were invented. The LED were more stable and cheaper, making the demand for LED’s rise significantly. The use of LED's became standard in various industrial applications in the 1990’s as the LED technology became more matured [10-12]. The high energy efficiency, long life and cost effective of LED lights have been gaining popularity and quickly replacing incandescent light sources.

1.3 Problem Statement

There are three problem statements of this research. Driving LED(s) at high output ripple and without current regulation can degrade LED(s) performance. Without the proper driver, high-brightness white LED may become unreliable and flickers, thus causing reduced performance or failure [13].

There are many type of energy losses that can reduce the energy efficiency in SMPS such as conduction loss, switching loss and controller or driver loss. Energy consumption on LED driver controller contributes to energy loss [14, 15]. As a result, energy efficiency of the LED driver reduces. Using low power device can help to minimize the energy loss during power conversion.

Identified limitations of prototyping of full custom ASIC requires time-consuming floor planning, place and route, timing analysis, and mask or re-spin stages process [16]. Plus, it does not reconfigurable or reprogrammable. Thus, fine tune and changes of the ASIC design cannot be done immediately.

Therefore, this study aimed to overcome the three problem statements and pursued towards more energy efficient and environmental friendly lighting system.

1.4 Research Objectives

The key objective of this research is to develop an LED driver for lighting application. Next objective that support to the key objective is to develop an LED driver controller which consists of PWM controller and current regulator using FPGA. The third objective is to analyse the performance of the developed LED driver in term of energy efficiency and output ripple.

1.5 Scope of Study

The scope divided into two parts which are development of LED driver simulation model and the development of LED driver prototype.

The first part of research scope is to design an LED driver model in SPICE software. LTSpice version 4.23e was used to design the LED driver simulation model. It consists of Power stage circuit, PWM controller and voltage mode control.

The second part of research scope covers the development of the LED driver prototype. Based on the simulation model design, a prototype was developed. FPGA was used as LED driver controller ASIC. Quartus II software and Verilog HDL was used to design the LED driver controller module.

The final part was to analyse both simulation model and hardware prototype in two experiments. The first experiment is to analyse the energy efficiency performance. The second experiment is to analyse the output ripple of the LED driver.

1.6 Significance of the Study

This study goal is to develop an LED driver with high energy efficiency using FPGA. This will help to promote the efficient use of electricity as stated in Malaysian Government Energy Commission act 2001 and Malaysian Government Electricity Supply Act 1990. This study also can be as a starting point for Malaysia to start wasting energy, improving energy usage and life quality.

In addition, this research will support other researchers on their results and help previous researchers on doing further advanced studies in this area. Other researcher can have more input and data that can be compared about the LED driver design. This would help other researcher to create higher energy efficiency LED lighting system as the world is adapting to renewable energy.

1.7 Organization of Thesis

This thesis consists of six chapters. The first chapter is introduction. The first chapter is the overview of the LED, problem statement, research objectives, scope of study and the significant of the study.

The next chapter is the literature review of the research which discusses about background information of the study and literature reviews of the research.

In the third chapter, explanations of the research methodology of this project is discussed. Overall project workflow from the first research works to the end are shown in this chapter.

The next chapter shows the development of the LED driver. This chapter explains about the development of LED driver simulation model and the development of the hardware prototype od LED driver.

In the fifth chapter, discusses the finding during. The chapter mostly shows experiment results and analysis of the LED driver simulation model and hardware prototype. In addition, this chapter also compares the result between the simulation model and hardware prototype.

Last chapter basically concludes the project based on the result and discussion in an earlier chapter. Besides, the future development on the project are also discussed in this chapter.

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