

**TRANSISTOR LEVEL IMPLEMENTATION OF LED DRIVER FOR SOLID
STATE LIGHTING**

by

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TABLE OF CONTENTS

	PAGE
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF FIGURES	ix
LIST OF TABLES	xvii
LIST OF SYMBOLS	xx
LIST OF ABBREVIATIONS	xxi
ABSTRAK	xxii
ABSTRACT	xxiii
 CHAPTER 1 - INTRODUCTION	
 1.1 Overview	 1
1.2 Problem Statement	2
1.2.1 Problem Identification	2
1.2.2 Significance of the project	3
1.3 Objectives	3
1.4 Scope of the work	4

1.4.1	The Relevancy of the Project	4
1.5	Thesis Organization	4
CHAPTER 2 - LITERATURE REVIEW		
2.1	Introduction	6
2.2	Voltage regulator and DC- DC Converter	6
2.3	Buck Converter	8
2.4	Buck converter based LED driver	12
2.4.1	Standard Buck Converter	13
2.4.2	Modified Buck Converter	14
2.5	Control Circuit for LED Driver	16
2.6	System on Chip	21
2.7	Summary	24
CHAPTER 3 – DESIGN METHODOLOGY		
3.1	Introduction	25
3.2	LED driver design flow chart	25
3.3	Method of LED driver design	27
3.3.1	Input Specifications	27

3.3.2	Simulation and development of discrete buck converter	28
3.3.2.1	Calculation of output voltage	30
3.3.2.2	Calculation of duty cycle	30
3.3.2.3	Selection of inductor	32
3.3.2.4	Selection of power switch	34
3.3.2.5	Selection of diode	36
3.3.2.6	Selection of output capacitor	38
3.3.3	Proposed Behavioral Model of LED Driver	39
3.3.3.1	Standard buck converter	40
3.3.3.2	Modified buck converter	43
3.3.4	Proposed Integrated LED Driver	44
3.3.4.1	Voltage Regulator	46
3.3.4.2	Oscillator	47
3.3.4.3	Feedback Circuit	50
3.3.4.4	Gate driver	51
3.4	Summary	53

CHAPTER 4 – IMPLEMENTATION

4.1	Introduction	54
4.2	Simulation and development of discrete buck converter	54
4.3	Modeling LED driver blocks using verilog A	62
4.3.1	Error Amplifier	62
4.3.2	Ramp and repeater	64
4.3.3	PWM comparator	66
4.3.4	One shot oscillator and SR Latch	67
4.4	Transistor Level Implementation using X-Fab XDM10 Process Technology	70
4.4.1	Voltage regulator	70
4.4.2	Vref bias circuit	73
4.4.3	Vref startup	76
4.4.4	Vref amplifier	79
4.4.5	Vref Bandgap	82
4.4.6	Regulator (LDO)	85
4.4.7	Bias 5V	86

4.4.8	Inverter gate	88
4.4.9	Nand gate	89
4.4.10	Comparator	90
4.4.11	SR Latch	91
4.4.12	Oscillator bias	92
4.4.13	Oscillator charge discharge	94
4.4.14	One shot buffer	95
4.4.15	One shot XOR	96
4.4.16	Error Amplifier	98
4.4.17	Gate Driver	99
4.5	Summary	101

CHAPTER 5 - RESULTS AND DISCUSSION

5.1	Introduction	102
5.2	Simulation and development of discrete buck converter results	102
5.2. 1	Standard buck converter	104
5.2. 2	Modified buck converter	110
5.3	Behavioral modeling results	115

5.3.1	Standard buck converter	118
5.3.2	Modified buck converter	122
5.4	Transistor implementation results	126
5.4.1	Internal regulated voltages and input signal	126
5.4.2	Modified buck converter	135
5.5	Summary	138

CHAPTER 6 - CONCLUSION AND RECOMMENDATIONS

6.1	Conclusion	139
6.2	Recommendations and future works	140

REFERENCES

APPENDICES

LIST OF FIGURES

Figure 2.1:	Basic linear regulator	6
Figure 2.2:	Basic switching regulator	7
Figure 2.3:	Buck converter circuit	8
Figure 2.4:	Typical waveforms in the converter under the assumption that the inductor is always positive	9
Figure 2.5:	Buck converter operation,	
	a. Off state when the switch is opened	10
	b. On state when the switch is closed	10
Figure 2.6:	Standard buck converter based LED driver	13
Figure 2.7:	Modified buck converter based LED driver	14
Figure 2.8:	Modified buck converter operation,	
	a. Off state when the switch is opened	15
	b. On state when the switch is closed	15
Figure 2.9:	Block diagram of control circuit	18
Figure 2.10:	Schematic cross sections of DMOS	23

Figure 3.1:	Flow chart of designing LED driver IC	26
Figure 3.2:	Proposed prototype of standard buck converter based LED driver	28
Figure 3.3:	Proposed Prototype of Modified Buck converter based LED driver	29
Figure 3.4:	PWM signals with different duty cycles	32
Figure 3.5:	Sawtooth signal of the average current	35
Figure 3.6:	Diode symbol	36
Figure 3.7:	Real power diode current	37
Figure 3.8:	Proposed control circuit for LED driver IC	40
Figure 3.9:	Bootstrap circuit for standard buck converter of LED driver	41
Figure 3.10:	Modified buck converter based LED driver	44
Figure 3.11:	Transistor top level design of LED driver IC	45
Figure 3.12:	Block diagram of voltage regulator	46
Figure 3.13:	Block Diagram of oscillator	47
Figure 3.14:	Block diagram of ramp generator	48
Figure 3.15:	Ramp and pulse signal	49
Figure 3.16:	Block diagram of feedback	50

Figure 3.17: Block diagram of gate driver	51
Figure 3.18: Gate charge characteristics	52
Figure 4.1: Schematic to test LED characteristic	54
Figure 4.2: I-V curve of LED	55
Figure 4.3: Schematic of standard buck converter	56
Figure 4.4: Schematic of modified buck converter	56
Figure 4.5: IRG4PC50UD pin configuration	57
Figure 4.6: HCPL-3140 pin out configuration	58
Figure 4.7: Diode STTH12R06	59
Figure 4.8: Lumispot White LED	60
Figure 4.9: Pin out for PIC16F877A	60
Figure 4.10: Standard buck converter development	61
Figure 4.11: Modified Buck converter development	61
Figure 4.12: Error Amplifier Block	63
Figure 4.13: Sawtooth waveform of VRAMP	64
Figure 4.14: Ramp and repeater block	64
Figure 4.15: PWM Comparator Block	66

Figure 4.16: SR Latch Block	68
Figure 4.17: Series regulator circuit	71
Figure 4.18: Biasing circuit	74
Figure 4.19: Startup circuit	77
Figure 4.20: Vref amplifier	79
Figure 4.21: Bandgap reference topology	82
Figure 4.22: Vref Bandgap	83
Figure 4.23: Regulator LDO	85
Figure 4.24: Bias 5V circuit	87
Figure 4.25: Inverter circuit	88
Figure 4.26: NAND gate circuit	89
Figure 4.27: Comparator circuit	90
Figure 4.28: SR latch circuit	92
Figure 4.29: Oscillator bias circuit	93
Figure 4.30: Oscillator charge discharge circuit	94
Figure 4.31: Decision level of sliced input signal for the output width	95
Figure 4.32: One shot buffer	96

Figure 4.33: XOR circuit	97
Figure 4.34: Error amplifier circuit	98
Figure 4.35: Gate driver circuit	100
Figure 5.1: I-V characteristics of LED	103
Figure 5.2: Simulated Waveforms of Emitter Voltage and Output voltage	105
Figure 5.3: Simulated Waveforms of Output current	105
Figure 5.4: Experimental Waveforms of Emitter Voltage and Output voltage	106
Figure 5.5: Output voltage and Input voltage result	108
Figure 5.6: Output voltage and Output current result	108
Figure 5.7: Experimental graph of Buck converter with different load	109
Figure 5.8: Simulated Waveforms of Collector Voltage and Output voltage	111
Figure 5.9: Simulated Waveforms of Output current	111
Figure 5.10: Experimental waveform for input voltage and output voltage	112
Figure 5.11: Output voltage and Input voltage result	113
Figure 5.12: Output voltage and Output current result	114
Figure 5.13: Experimental graph of Modified Buck converter with different load	115

Figure 5.14: Simulation result of error amplifier block	116
Figure 5.15: Simulation result of ramp and repeater block	116
Figure 5.16: Simulation Result of PWM Comparator Block	117
Figure 5.17: Simulation result of SR latch	117
Figure 5.18: Simulation result of ILED and VLED for bootstrap mode LED driver for different V_H with $V_L = 0.2V$, gain = 1	119
Figure 5.19: Simulation result of ILED and VLED for bootstrap mode LED driver for different V_H with $V_L = 0.2V$, gain = 10	120
Figure 5.20: Simulation result of ILED and VLED for bootstrap mode LED driver for different V_H with $V_L = 0.2V$, gain = 100	121
Figure 5.21: Uncontrolled outputs of LED driver with 50% duty cycle of one shot signal, D_{SHOT} and 19% duty cycle of buck, D_{BUCK}	122
Figure 5.22: Simulation result of ILED and VLED for modified buck converter LED driver for different V_H with $V_L = 0.2V$, gain = 1	123
Figure 5.23: Simulation result of ILED and VLED for modified buck converter LED driver for different V_H with $V_L = 0.2V$, gain = 10	124
Figure 5.24: Simulation result of ILED and VLED for modified buck converter LED driver for different V_H with $V_L = 0.2V$, gain = 100	125

Figure 5.25: a. Pre layout simulation result of vdda5	127
b. Post layout simulation result of vdda5	128
Figure 5.26: a. Pre layout simulation result of vh	128
b. Post layout simulation result of vh	129
Figure 5.27: a. Pre layout simulation result of vl	129
b. Post layout simulation result of vl	130
Figure 5.28: a. Pre layout simulation result of vref0.4	130
b. Post layout simulation result of vref0.4	131
Figure 5.29: a. Pre layout simulation result of ramp	132
b. Post layout simulation result of ramp	132
Figure 5.30: a. Pre layout simulation result of clock signal	133
b. Post layout simulation result of clock signal	133
Figure 5.31: a. Pre layout simulation result of one shot signal	134
b. Post layout simulation result of one shot signal	134
Figure 5.32: a. Pre layout simulation result of I_{LED} and V_{LED}	135
b. Post layout simulation result of I_{LED} and V_{LED}	136
Figure 5.33: a. Pre layout simulation result of I_{LED} and V_{LED} ripples	136

LIST OF TABLES

Table 3.1:	Specifications of LED driver	27
Table 4.1:	Input parameters for Simulation and development of discrete buck converter	55
Table 4.2:	Input parameters for behavioral modeling and transistor design of buck converter	62
Table 4.3:	Values of input parameters for error amplifier	63
Table 4.4:	Values of input parameters for ramp and repeater	65
Table 4.5:	Values of input parameters for PWM comparator	66
Table 4.6:	Values of input parameters for one shot signal and SR latch	67
Table 4.7:	Aspect ratios and values of series regulator	73
Table 4.8:	Aspect ratios and values of Bias Circuit	76
Table 4.9:	Aspect ratios and values of Startup Circuit	79
Table 4.10:	Aspect ratios and values of Amplifier Circuit	82
Table 4.11:	Aspect ratios and values of Bandgap core Circuit	84
Table 4.12:	Aspect ratios and values of Regulator LDO	86
Table 4.13:	Aspect ratios and values of Bias 5V	87

Table 4.14:	Truth table of NOT gate	88
Table 4.15:	Aspect ratios and values of inverter.	89
Table 4.16:	Truth table of NAND gate	89
Table 4.17:	Aspect ratios and values of NAND gate	90
Table 4.18:	Aspect ratios and values of Comparator	91
Table 4.19:	Truth table of SR latch	92
Table 4.20:	Aspect ratios and values of Oscillator Bias	93
Table 4.21:	Aspect ratios and values of Oscillator Charge Discharge	95
Table 4.22:	Aspect ratios and values of One Shot Buffer	96
Table 4.23:	Truth table of XOR gate	97
Table 4.24:	Aspect ratios and values of Error Amplifier	99
Table 4.25:	Aspect ratios and values of Gate Driver.	100
Table 5.1:	Experimental result to test LED characteristic	103
Table 5.2:	Total static resistance for different number of LED	104
Table 5.3:	Simulation results of Buck converter	107
Table 5.4:	Experimental result of Buck converter with resistor	107
Table 5.5:	Experimental result of Buck converter with LEDs	109

Table 5.6:	Simulation result of Modified Buck converter	112
Table 5.7:	Experimental result of Modify Buck converter	113
Table 5.8:	Experimental result of Modified Buck converter with LEDs	114
Table 5.9:	Parameter Set in The Simulation	118
Table 5.10:	Parameter Set in the Simulation	112
Table 5.11:	LED drivers' performance parameters	126
Table 5.12:	Desired values of regulated voltage	127
Table 5.13:	Reference voltages and input signal of modeling and IC design	135
Table 5.14:	LED drivers' performance parameters	137

LIST OF SYMBOLS

μ	Micro
f	Frequency
Hz	Hertz
$^{\circ}$	Degree
Ω	Ohm
Δ	Delta
λ	Lambda
β	Beta
ω_{ta}	Unity gain frequency
τ	Time Constant
η	Efficiency

LIST OF ABBREVIATIONS

AC	Alternating Current
BJT	Bipolar Junction Transistor
CCM	Continuous Current Mode
DC	Direct Current
IGBT	Insulated Gate Bipolar Transistor
LED	Light Emitting Diode
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
PWM	Pulse Width Modulation
RMS	Root Mean Square
SMPS	Switched Mode Power Supply
SSL	Solid State Lighting
SoC	System on Chip

PELAKSANAAN PERINGKAT REKA BENTUK TRANSISTOR SEBAGAI PEMACU DIOD PEMANCAR CAHAYA UNTUK APLIKASI PENCAHAYAAN KEADAAN PEPEJAL

ABSTRAK

Tesis ini mengemukakan pelaksanaan reka bentuk transistor sebagai pemacu Diod Pemancar Cahaya (LED) untuk aplikasi Pencahayaan Keadaan Pepejal (SSL). SSL merujuk kepada jenis pencahayaan yang menggunakan LED jenis semikonduktor, organik (OLED), atau polimer (PLED). Pemacu LED adalah alat elektrik yang menyalurkan jumlah kuasa yang berterusan kepada keperluan LED. Penukar 'buck' adalah jenis penukar DC ke DC yang boleh menurunkan voltan input DC kepada voltan yang diperlukan LED. Untuk aplikasi voltan masuk daripada 220-240V AC yang telah ditukar ke voltan DC, teknik penukar 'buck' yang diubahsuai telah diaplikasikan berbanding penukar buck konvensional yang memerlukan reka bentuk 'bootstrap' yang lebih kompleks. Prototaip pemacu LED dibangunkan untuk membuktikan operasi penukar 'buck'. Reka bentuk litar 'buck' telah digabungkan di dalam IC untuk menyalurkan arus keluar berterusan kepada LED dengan tujuan untuk mengurangkan saiz, berat dan kos. Reka bentuk IC sebagai pemacu LED bermula dengan teknik model perilaku bagi litar pengawal dengan integrasi suis kuasa, DMOS. Parameter yang telah diperolehi daripada model perilaku telah diaplikasi pada peringkat reka bentuk transistor menggunakan teknologi X-Fab XDM10, 1.0 μ m 350V. 20 LED bersiri diaplikasi dengan keluaran voltan sebanyak 50-60V dan arus 350mA. Keputusan arus keluaran daripada model perilaku adalah 348mA berbanding keputusan simulasi pre dan pos 'layout' yang masing-masing 344mA dan 350mA bagi peringkat reka bentuk transistor. Ini menunjukkan model perilaku boleh membuktikan sistem yang cepat dan lebih baik untuk dilaksanakan di peringkat reka bentuk transistor.

TRANSISTOR LEVEL IMPLEMENTATION OF LED DRIVER FOR SOLID STATE LIGHTING

ABSTRACT

This thesis presents the transistor level implementation of LED driver for Solid State Lighting (SSL). SSL refers to a type of lighting that uses semiconductor light emitting diodes, organic light emitting diodes (OLED), or polymer light emitting diodes (PLED) as sources of illumination. LED driver is an electrical device that provides required LED voltage and regulates the constant amount of power to the needs of LED or string of LED. A buck converter is one type of DC- DC converter that can step down the DC input voltage to the required LED voltage. In the high input voltage application of the rectified 220-240V AC, the modified buck converter technique has been applied instead standard buck that requires complicated design of bootstrap mode. The development of discrete LED driver prototype is to prove the buck converter operation. This circuit design has been integrated with the LED driver Integrated Circuit (IC) to provide a constant current output to the LEDs with the intention to decrease the size, weight and cost. The design of LED driver IC is started with the behavioral modeling technique for proposed control circuit with integrated power switch, DMOS. The obtained parameters from behavioral model have been implemented in the transistor level design using X-Fab XDM10 1.0 μ m 350V process technology. In this project, LEDs string will be driven as much as 20 with the total forward voltage are 50-60V and the current is 350mA. The results of regulated output current from behavioral modeling is 348mA has been compared with pre and post layout simulation results in transistor level design that are 344mA and 350mA respectively. It shows that behavioral model can verify the better system of the transistor implementation for LED driver IC with integrated DMOS.

CHAPTER 1

INTRODUCTION

1.1 Overview

Efficient, affordable and long-lasting alternative is required to enhance the performance of artificial lighting. Solid State Lighting (SSL) shows a great promise that meets these features (Azevedo, Morgan, M.G & Morgan, F., 2009). SSL devices, such as light emitting diodes (LEDs) and organic LEDs (OLEDs) have improved rapidly. Most important advantages of inorganic LEDs are their very high lifetimes, the controllability (color control and dimming), saturated colors, robustness, small size and high efficacy (Jacobs, Shen Jie and Hente, 2008).

Compared with fluorescent lamps, an attractive feature of LEDs is longevity, which is typically 100,000 hours (Baddela and Zinger, Nov 2004), (Calleja, Ricosecades, Cardesin, Ribas, and Corominas, 2004). The lifetime expectancy is much longer than that of fluorescent lamps, typically 10,000 - 20,000 hours. Fluorescent lamp, although much more efficient than an incandescent light bulb, are not really very environmentally friendly. Fluorescent bulbs are made with mercury and pose a danger to our environmental health. There is currently no efficient recycling program for these toxic fluorescent bulbs. The mercury then seeps into our water tables and becomes a part of our environmental food chain that surely not a very green choice. LED light bulbs are the most environmentally friendly light source.

As the LED technology evolves, the possibilities for new and more intelligent products enlarge the demand for more specific features from the controller-based

LED drivers. The applications involving LEDs are innumerable and its varieties impose a clear demand on design of controllable LED drivers.

LED driver is an electrical device that regulates the power to an LED or LED in series. It responds to the ever-changing needs of the LED, by supplying a constant amount of power to the LED as its electrical properties change with temperature compares with conventional power supplies (Siyuan Zhou, Gabriel A., and Rincon-Mora, Apr 2006), (Bonizzoni, Borghetti, Malcovati, Maloberti, and Niessen ., Feb 2007) and (Nagaraja, Kastha, and Patm, May 2005). The standard supply is 220V AC - 240 V AC at 50-60 cycles. These AC voltages will be rectified to DC voltages.

A buck converter is a DC-DC converter that steps down DC input voltage to a required DC output voltage (Isurin and Cook, Mar 2006). This type of converter is better when considering transformer losses, and higher commutation frequency significantly can reduce the size of the transformer, decreases prices, and increases the efficiency.

1.2 Problem Statement

1.2.1 Problem Identification

The design requires high input voltage and the LEDs required low voltage from the output voltage. Application of a single white LED as a portable lighting device requires a high driving forward voltage and a high driving current. A white LED is a current driven device whose brightness is proportional to the conduction current. The conduction current is normally regulated to avoid exceeding the rated maximum current and to obtain a constant luminous intensity (Chi-Hao Wu, Chern-Lin Chen, Oct 2009). In order to decrease the size and weight of these devices, miniaturization

of the power modules is essential. As a result, the trend is to focus on CMOS implementation of converters (Lee and Mok , May 2002).

1.2.2 Significance of the project

The focus of this project is to implement an appropriate method to develop LED driver IC that can drive the LEDs from high voltage input and produced constant current output. Behavioral modeling technique is faster and better system verification method to develop an IC.

The conventional LED driver IC accepts very low input voltage and increase the size LED driver with the discrete components of the external voltage regulator. The off-chip switching transistor also increases the component count hence increase the cost. In this project with the high input voltage application of the rectified 220-240V AC, the modified buck converter technique has been applied instead standard buck that requires complicated design of bootstrap mode when integrating high voltage switching transistor, Double-diffused Metal Oxide Semiconductor (DMOS). The proposed LED driver IC with high voltage input allows the internally built-in voltage regulator into one chip that reduces the size and cost of the LED driver.

1.3 Objectives

This project is carried out for the following objectives:

- i. To design and develop behavioral modeling of LED driver IC with constant 350mA output current.
- ii. To design and implement modeled parameters of LED driver IC with the integrated 350V high voltage DMOS using XFab's XDM10 technology.

1.4 Scope of the work

The scope of the project is focused on the designing buck converter for converting high DC voltage supply to the required forward voltage with constant current outputs to the LEDs. Then, the modeled parameters of the control circuit from behavioral modeling are implemented in transistor level design.

1.4.1 The Relevancy of the Project

Low cost solutions for designing LED driver IC with reducing verification complexity of transistor design and effort required using behavioral modeling technique. The subsystem architecture verification with integration of the actual DMOS model is an attempt to employ mixed-signal system efficiently and cost effectively to address simulation challenges of complex designs.

1.5 Thesis Organization

Chapter 1 comprises of the overview of the project, problem statement, objectives, scope of the project and project guidelines.

Chapter 2 summarizes the literature review for the LED driver design. Buck converter theory and operations are explained in this chapter. The prototype of buck converter and the simplified operation of a control circuit for LED driver have been discussed.

Chapter 3 cover the methodology used for this project. The road map and flow chart of the design have been discussed within this chapter. This chapter described the buck converter, block diagrams of a control circuit and transistor level design for LED driver.

Chapter 4 is the development of the LED driver prototype, implementation of behavioral model using Verilog A language and transistor level design using XDM10 technology.

Chapter 5 are results and discussions. The buck converter prototype results have been analyzed. This result implies the design of a control circuit for buck converter. Behavioral model results have been compared with transistor level results.

Chapter 6 is the conclusion for the achievement of the objectives. Furthermore, this chapter includes a brief statement of successfulness and future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the comparison of conventional voltage regulator and DC-DC converter will be focused as in section 2.2. In section 2.3 the details of buck converter will be discussed. Topology of buck converter based LED driver is divided into two modes, standard mode and modified mode as explained in section 2.4. Thereafter, sections 2.5 and 2.6 have reviewed the control circuit for LED driver and implementation of this control circuit as a system on chip.

2.2 Voltage regulator and DC- DC Converter

Two categories of regulating voltage are a linear regulator and a switching regulator. The conventional voltage regulator as a linear regulator in Figure 2.1 has been replaced with switching regulator that provides high efficiency, low loss heat and smaller size. The resistance of the linear regulator varies in accordance with the load resulting in a constant output voltage .

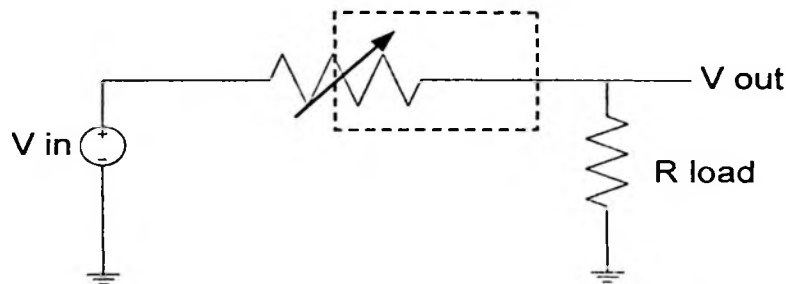


Figure 2.1: Basic linear regulator

The switching regulator as shown in Figure 2.2 ideally has no resistance or very low resistance. The basic operation is no current flow when the switch is open

and no voltage drop when the switch is closed. Since power is a product of current and voltage, no losses occur in the switch. In comparison to a linear regulator, switching regulator is much more efficient than the linear regulator by achieving efficiencies as high as 80% to 95% while a linear regulator usually exhibits only 50% to 60% efficiency (Muhammad Saad Rahman, 2007). Switched mode power supply or pulse signal can also step down or step up the input voltage. This regulator is the basis of all DC- DC converters.

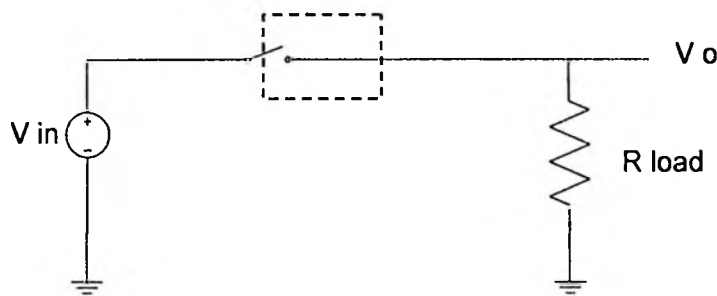


Figure 2.2: Basic switching regulator

The DC- DC converter is powered electronic circuit that converts DC input voltage to a different voltage level. Currently, DC- DC converters can be divided into two categories, which are non-isolated and isolated DC- DC converters (Muhammad Saad Rahman, 2007). The non-isolated DC- DC converter has a DC path between its input and output and without the AC power line. Buck converter, boost converter and buck-boost converter are the basis of non-isolated DC- DC converters. The isolated DC- DC converter is switched mode power supply. An isolated converter employs a transformer to provide DC isolation between input and output voltage, which eliminates the path between the two. The high-frequency transformer and inductor design need for this converter.

Minimum additional components are needed for integrated circuits of DC-DC converters. The available integrated DC-DC converters as a complete circuit and system are ready for use within an electronic assembly.

2.3 Buck converter

A buck converter is a step-down DC-DC converter. It is designed to step down the voltage with a switched-mode power supply that uses two switches with LC filter (Rashid, 2006).

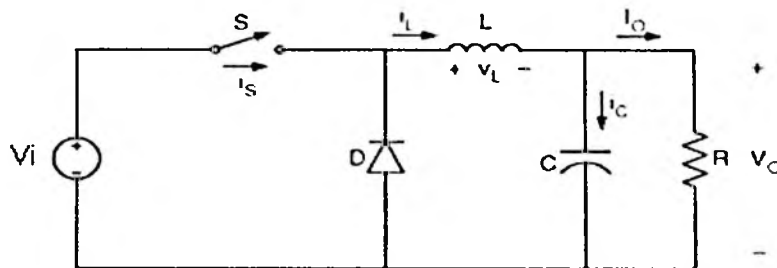


Figure 2.3: Buck converter circuit diagram

The buck converter as shown in Figure 2.3 consists of DC input voltage source V_i , controlled switch S , diode D , filter inductor L , filter capacitor C , and load resistance R . The operation of the buck converter is fairly simple. It alternates between connecting the inductor to source voltage to store energy in the inductor and discharging the inductor into the load.

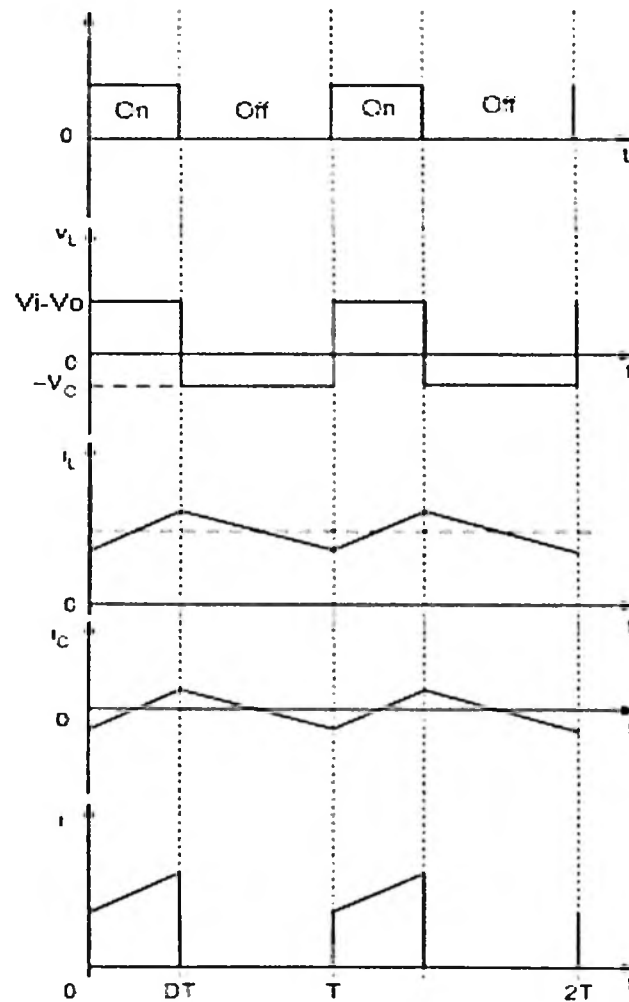
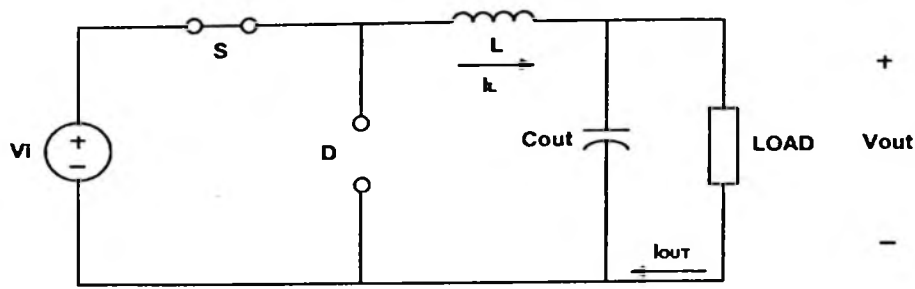
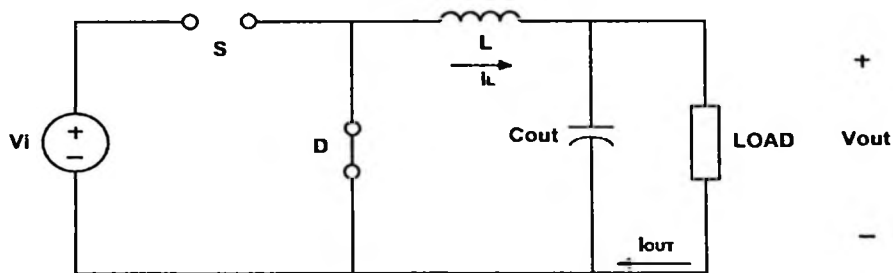


Figure 2.4: Typical waveforms in the converter under the assumption that the inductor current is always positive.



a.



b.

Figure 2.5: Buck converter operation, a. Off state when the switch is opened; and b.

On state when the switch is closed

As shown in Figure 2.4, the state of the converter in which the inductor current is never zero for any period of time is called the continuous conduction mode (CCM). It can be seen from the Figure 2.5 a., when the switch, S commands to the on state, the diode D is reverse biased and from Figure 2.5 b., when the switch S is off, the diode conducts to support an uninterrupted current in the inductor.

The relationship between the input voltage, output voltage, and the switch duty ratio D can be derived, for instance, from the inductor voltage, V_L . When the converter's switch is on,

$$V_L = V_i - V_o \quad (2.1)$$

So the inductor voltage V_L is positive. This means the current through the inductor will increase. When the switch is off,

$$V_L = -V_o \quad (2.2)$$

So the current through the inductor will decrease. According to Faraday's law, the inductor volt-second product over a period of steady state operation is zero. For the buck converter,

$$(V_i - V_o)DT = -V_o(1-D)T \quad (2.3)$$

Hence the DC voltage transfer function, defined as the ratio of the output voltage to the input voltage, is

$$D = \frac{V_o}{V_i} \quad (2.4)$$

It can be seen that the output voltage is always smaller than the input voltage (Rashid, 2006).

Higher efficiency, good load and line regulation are required for DC-DC converter. Efficiency is the ratio of output power and input power as in equation (2.5). The power consumption of internal control circuits and power MOSFETs is the difference between input power and output power. Low for the light load application will result in a lower efficiency. Therefore, when the buck converter is overloaded with a given large output current, the efficiency is relatively high (Wang, Chen, Sung and Wang C. L., Feb 2011).

$$\text{Efficiency} = \frac{P_{out}}{P_{out} + P_{loss}} \times 100\% \quad (2.5)$$

Line regulation is expressed as a ratio of the variation in the output voltage relative to that in the input voltage, while the load regulation is expressed as a variation in the steady state output voltage when the load current changes (Wang, Chen, Sung and Wang C. L., Feb 2011). Equation (2.6) and (2.7) show the definition for line regulation and load regulation, respectively.

$$\text{Line regulation} = \frac{\Delta V_{\text{out}}/V_{\text{out}}}{\Delta V_{\text{in}}} \times 100\% \quad (2.6)$$

$$\text{Load regulation} = \frac{\Delta V_{\text{out}}/V_{\text{out}}}{\Delta I_{\text{out}}} \times 100\% \quad (2.7)$$

Buck converter can be remarkably efficient (up to 95 % for integrated circuits) and self-regulating (Kaiwei, Mao, Ming, & Lee, 2005). This topology can be used not only to convert the voltage, but is also suitable to act as a current source, depending on the control method. In application of LED driver using high-voltage input, the buck converter will step down the input voltage to the lower output voltage according to LEDs string voltage.

2.4 Buck converter based LED driver

Buck converter is ideal for LED driver applications where the input voltage is always higher than the LED voltage, as in many automotive or industrial applications. Constant current driver is required to drive LED (Steve Winder, 2008). This buck converter with the control circuit to control the current will offers the highest efficiency, lowest noise, and the reduced size. There are two buck converter topologies for LED driver, standard and modified buck converter.

2.4.1 Standard Buck Converter

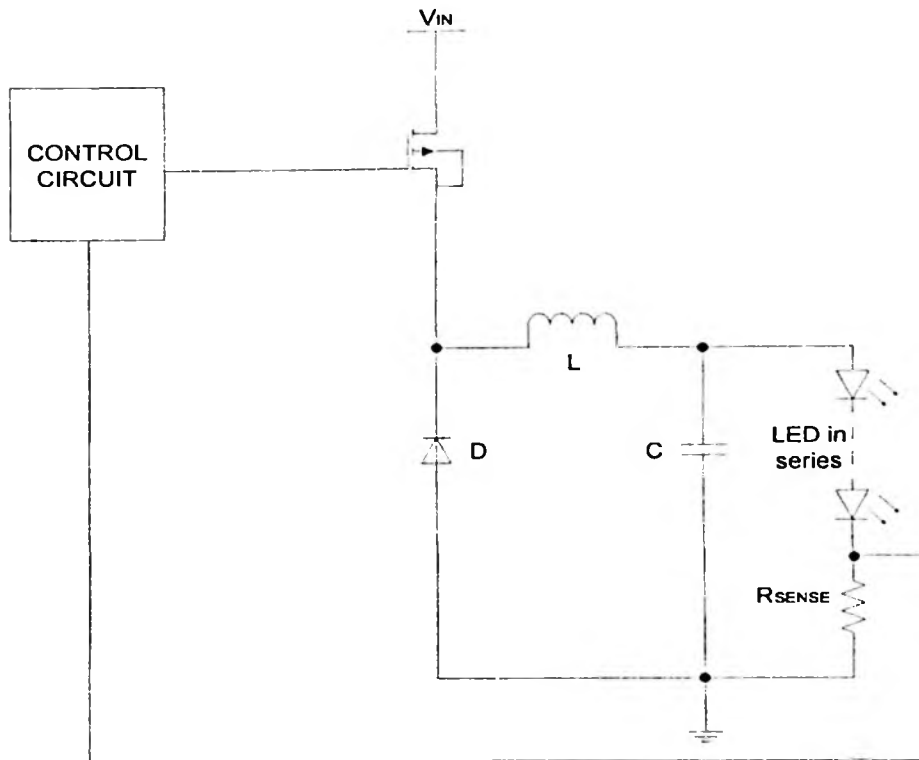


Figure 2.6: Standard buck converter based LED driver.

Standard buck converter based LED driver as shown in Figure 2.6 is a basic DC-DC buck converter design. The operation of this topology based on basic operation of buck converter in Figure 2.5a. and 2.5b.. As the requirements for LED driver to provide a constant current output to the LED, control circuit and sense resistor, R_{sense} are needed. The control circuit will allow the current to flow from the input to the LED to turn on the transistor until it meets the expected current. After the current is met, the control circuit will generate the required duty cycle of the PWM signal to provide the LED voltage (Wang, Chen, Sung and Wang C. L., Feb 2011).

2.4.2 Modified Buck Converter

A modified buck topology was chosen as the solution to control the switch. The source of power switch is connected to ground rather than the standard buck that is drive the LED at the source side. This allows the control circuit to drive the circuit at the drain side. Using this method, LED voltage can be higher than gate voltage of the power switch compared to the standard buck that only provide the LED voltage less than gate voltage (Steve Winder, 2008). The modified buck converter is a step down DC-DC converter same concept as a basic concept of buck converter.

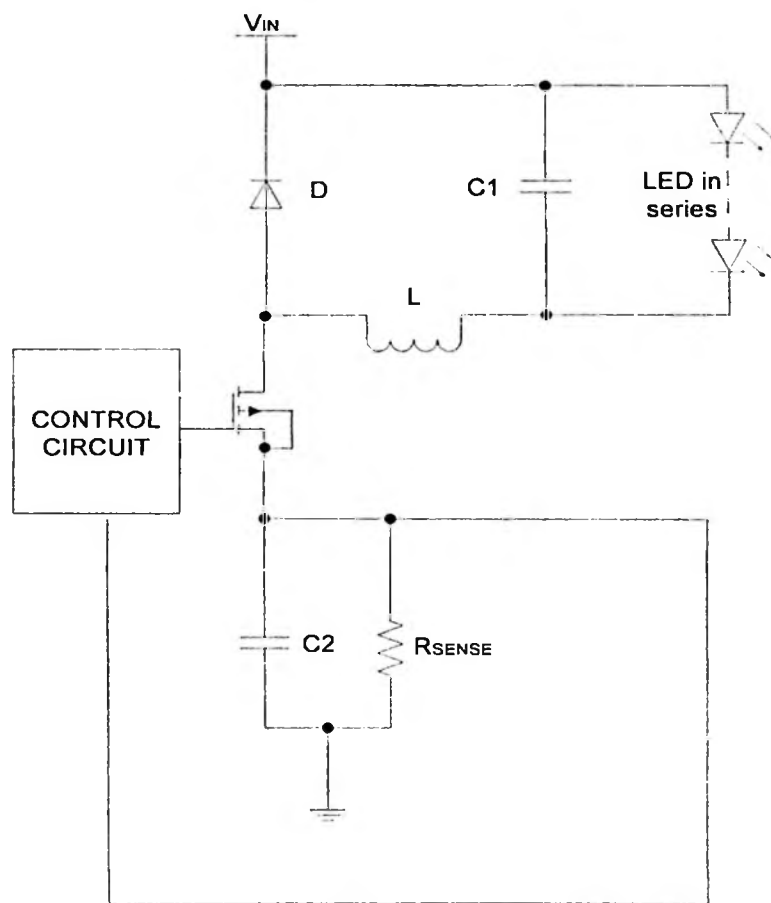
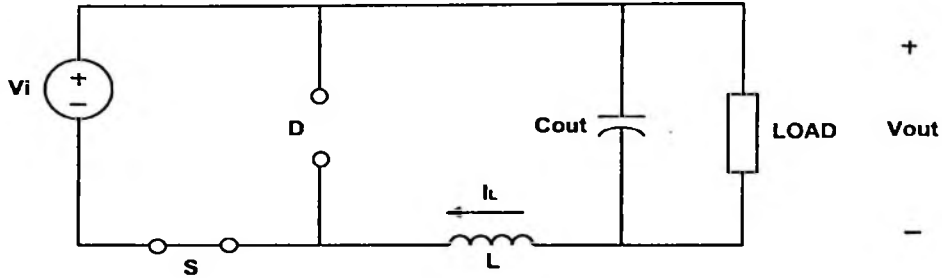


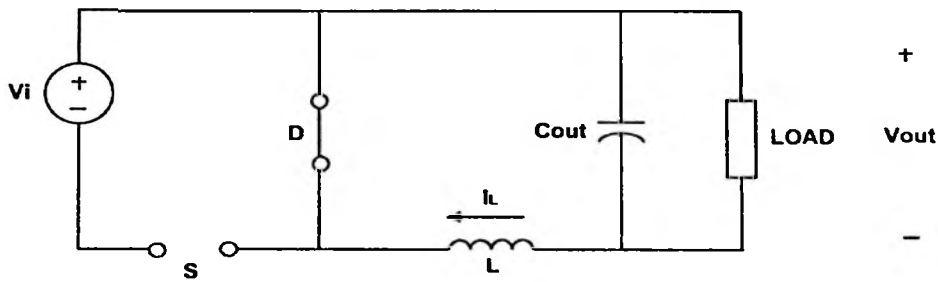
Figure 2.7: Modified buck converter based LED driver.

Figure 2.7 shows a simplified modified buck converter that accepts a DC input to the diode. The switching transistor for this topology drives the diode, D ,

inductor, L , capacitor, $C1$ and LED on the high side and allows current to flow through the sense resistor, R_{sense} at the low side. $C2$ is needed to regulate the switching voltage.



a.



b.

Figure 2.8: Modified buck converter operation, a. Off state when the switch is open; and b. On state when the switch is closed.

As shown in Figure 2.8a., when the switch S is commanded to the on state, the diode D is reverse biased and from Figure 2.8b., when the switch S is off, the diode conducts to support an uninterrupted current in the inductor. The relation between V_L and I_L is referring to a basic buck operation in equation (2.1) and operations of modified buck converter during ON state same as equation (2.2).

Since in CCM mode, the inductor current change during ON and OFF is the same so the duty cycle for the modified buck topology also same as standard buck topology using equation (2.4). LED voltage of the modified buck converter is using equation (2.8),

$$V_{LED} = V_{IN} - V_L \quad (2.8)$$

The modified buck converter can be used for lighting applications from low power and low voltage, to high power and high voltage. This allows the LED driver design to cover a wide range of different LED systems using a single topology (Steve Winder, 2008).

2.5 Control Circuit for LED Driver

The LED driver needs to control the constant current output that maintains brightness of LEDs. In SSL applications, white LED is a current driven device whose brightness is proportional to the conduction current. The relationship between current and luminous flux is linear and the impact of the ambient temperature on the luminance-current characteristic is less than the impact on the voltage-luminance characteristic. The conduction current is normally regulated to avoid exceeding the rated maximum current and to obtain a constant luminous intensity (Chi-Hao Wu, Chern-Lin Chen, Oct 2009).

System level design of an LED driver has been discussed in (Zheng Jiuyun, Han Zhigang & Luo Shengqian, 2009) and (Zhang Tong, Yang Yuan, Song Zhenghua & Fan Yongbo, 2012) but the methodology of the efficient verification did not mention in this paper. The advanced methodologies for mixed-signal IC systems are required to design and verify SMPS (Ji Eun Jang, Myeongjae Park & Jaeha Kim,

2013). In consideration of power, cost, and size when used in applications such as LED drivers (Broeck, Sauerlander, and Wendt , 2007), and on-chip power management systems (Patounakis, Li and Shepard, 2004), the large portion of switching regulators is being realized in ICs. The cost of power supplies on chip (Kudva and Harjani, 2011) brought the changes to the discrete components based switching regulator design when it is no longer set by the component count, and the implementation of many controllers supports multiple operating modes and maintain high efficiency in different conditions.

Using SPICE or mixed-signal simulator for verifying the analog design can be both slow and expensive while digital design are efficiently verified using HDL simulators. This method can take a long time and slow feedback loops that have long time constants for conditioning the response to run SPICE analysis on high-performance circuits.

PSPICE modeling of a commercial LED driver has been proposed in (Yun-Jae Yi, Yu & Yun-Seop Yu, 2011). According to (Ji Eun Jang, Myeongjae Park & Jaeha Kim, 2013), behavioral modeling technique suited for integrated switching power supplies that typically comprise a complex mixed-signal system with an analog power converting stage and a digital controller. Verilog can serve as a true event-driven simulation engine in the integration of analog and digital models. Compared to other Hardware Description Language (HDL), Verilog offers a composite data type and hence the set of multiple parameters to be exchanged between the block modules as though they are a single bundled signal.

A control circuit is part of LED driver design to control the LED voltage and current. The standard control circuit includes an input coupled to receive a DC

supply voltage, a pulse width modulator and a feedback circuit input operable to indicate the LED current.

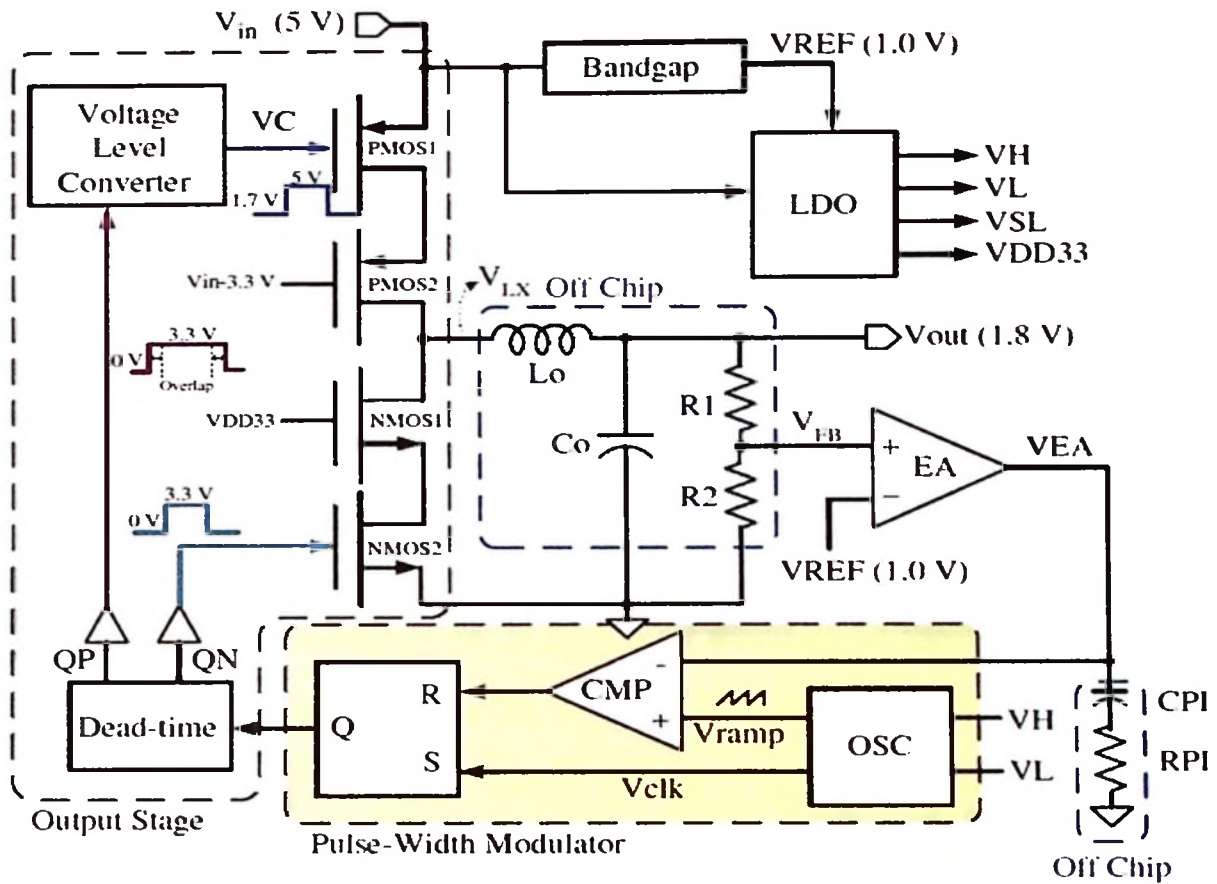


Figure 2.9: Block diagram of control circuit (Wang, Chen, Sung and Wang C. L., Feb 2011).

As shown in Figure 2.9, on-chip block diagram is a control circuit. The control circuit consists of error amplifier (EA), pulse width modulator that are included oscillator (OSC) to generate clock and ramp signal, voltage comparator (CMP) and SR latch, transistors for output stages and low dropout linear regulator (LDO) with the bandgap.

Pulse width modulator is used to realize the feedback control. The pulse width modulator is operable to control the pulse width of the modulation (PWM) applied to the buck converter circuit that control LED voltage depending upon the

LED current as it is detected by the feedback signal. In achieving high power efficiency and constant current, the PWM technique is often employed in the LED driver. PWM is a technique in which a series of digital pulses is used to control an analog circuit. The length and frequency of these pulses determine the total power delivered to the circuit. PWM signals are most commonly used to control DC motors, but have many other applications ranging for controlling the brightness of an LED. The PWM strategy switches modes between PWM and Pulse Frequency Modulation (PFM) to reduce working frequency and improve power efficiency simultaneously when the load is changing. The control technique of PWM can achieve constant output current and high power efficiency while reducing complexity and cost.

The current - sense resistor is providing feedback to the control circuit. It is used to measure the current flowing in the LEDs. It should be large enough to generate a reasonable feedback voltage, V_F but it should also be small enough to limit its power dissipation. Multiple LEDs should be connected in a series configuration to keep an identical current flowing in each LED. Driving LEDs in parallel requires a ballast resistor in each LED string, which leads to lower efficiency and uneven current matching.

The LDO is a voltage source to supply to the internal circuitry and the generated reference voltage from the bandgap (Allen & Holberg ., 2002). This internally generated reference voltage, V_{REF} , is compared with a feedback voltage, V_{FB} which is the output voltage, V_{out} , divided by $R1$ and $R2$. A feedback circuit regulates the switching in the switching output. The feedback circuit cancels out any errors in the feedback voltage due to component or timing tolerance and it adjusts the duty cycle to compensate for changes in the load current. The result is a self-

regulating step-down buck converter that produces a stable LED voltage over constant currents. A faster speed of the feedback loop comes along with a more stable load voltage. The resulting current flow through the LEDs is a DC signal (Wang, Chen, Sung and Wang C. L., Feb 2011).

Error amplifier is used to amplify the difference between V_{REF} and V_{FB} . The output of the error amplifier, V_{EA} , is compared with V_{ramp} to generate a PWM control digital signal, Q . Typically, a high frequency signal will be coupled with the output voltage in switched mode power supply (SMPS) designs. The low frequency gain should be considered in this design with the filtered unwanted high frequency signals. Amplifiers with the higher bandwidth will amplify the unwanted control signal in high frequency range to cause the system loop unstable. Therefore, 1MHz bandwidth is more than enough to cope with the switching frequency of the SMPS design (Pressman, Billings and Morey, 2001; Luo & Ma, 2010).

Two non-overlapping signals, QP and QN are generated from the dead - time circuit. Voltage level converter (Rocha, Santos, Doris Costa and Lima, 2008) shifts the voltage level of QP and sends a VC to be the gate drive of the power transistor (PMOS1).

The switching frequency is dependent on the input voltage and load current. A higher switching frequency lowers the efficiency due to the increased switching losses (Hogue, Ahmad, McNutt, Mantooth, & Mojarradi, 2006). Input current magnitude can be controlled by switching frequency. This can be utilized for controlling the output voltage with the switching frequency. It should be noted that the increasing switching frequency reduces output voltage and vice versa (Liu Xin et al., 2009). The increase of switching frequency also increases the energy associated

with capacitive coupled displacement but high frequency switching result in smaller off-chip reactive components can be used leading to more savings on the bill-of-material (BOM). The BOM can be even further reduced if off-chip reactive components are eventually integrated. Resistive losses dominate at low frequency while capacitive losses are dominant at high switching frequencies (Emira, Carr, Elwan and Mekky, 2009).

The proposed control circuit as in Wang, Chen, Sung and Wang C. L., Feb 2011 have issues when the input voltage is higher than 5V and needs four switching transistor with dead-time circuit to drive the circuit. Therefore, the suggested modified buck converter with integrated one high voltage switching transistor allows high input voltage without dead-time circuit.

2.6 System on chip

System-on-a-chip (SoC) is the packaging of all the necessary electronic circuits and components for a system on a single chip or integrated circuit (IC). SoC technology is used in small and complex electronic devices. The application is in the area of embedded systems. SoC is evolving along with silicon-on-insulator (SOI), which can provide higher clock speeds while reducing the power consumed by a chip. Integration of features into the control IC is the single most important factor that contributes to a small-driver solution. The board area required would consume more space than the power supply itself if all the features were implemented with discrete components. SoC implementation significantly reduces the overall driver size while reducing the total solution cost. Component cost would increase if all desirable features are implemented discretely (Day, 2004).

CMOS technology enables more complex systems to be integrated on one die (Wens and Steyaert, 2009). In Very Large Scale Integration (VLSI) technology, CMOS has been chosen preferably over bipolar junction transistor (BJT) for its high integrability and relative low cost (Shuo-Mao Chen et al., 2004).

The switching frequency is one factor that contributes to the size of the circuit components. Higher switching frequencies allow the use of smaller passive components. Modern LED driver intended for portable applications should be able to switch at frequencies of up to 1MHz. Switching at frequencies greater than 1 MHz is not typically recommended because it will reduce the efficiency due to the higher switching losses. This higher switching frequency isn't significantly helping in intention to reduce the circuit size (Day, 2004).

For a wide variety of applications it is necessary to combine low voltage CMOS logic with high voltage power devices. A smart power device is the combination of low voltage CMOS logic with high voltage power devices in one and the same chip. In LED driver applications, this implementation offers the advantage that for each chip the best available process in terms of cost and technical features.

Two types of switching transistor for buck converter are DMOS and IGBT. DMOS transistors and IGBT supplies energy saving concepts and systems in power or high voltage integrated circuits technology. DMOS transistors consistently offer high performance at a competitive price. In Gehan Amaratunga & Florin Udrea (2001), the integration of high voltage power devices has the capability of MOS gate control for compatibility with on-chip CMOS drive. Therefore, the conductivity modulation of the high resistivity voltage blocking region is accomplished under MOS gate control. The DMOS is a unipolar device and hence

high commutation speed, but suffers from a high on-resistance, especially when rated above 100V while IGBT suffers from a slower switching speed. The applications of power integrated circuit as mentioned in Satyeen Mukherjee (1994) including TV power supply, communications products, automotive, audio and video amplifier, power supply controller, motor controller and electronic ballast for fluorescent lighting. LED driver applications in Zhang Tong, Yang Yuan , Song Zhenghua , Fan Yongbo, (2012), Qiu Jianping & He Lenian, (2010), and Yuan-Ta Hsieh, Bin-Da Liu, Jian-Fu Wu, Chiao-Li Fang, Hann-Huei Tsai, Ying-Zong Juang, (2010) are using the integrated low voltage devices.

DMOS is one device in XDM10 technology. XDM10 offers an X-Fab's dielectric trench insulated smart power technology and the targeted applications are analog switch ICs, driver ICs for capacitive, inductive and resistive loads and EL or piezo driver ICs. The typical breakdown voltage of the High Voltage Double-diffused Metal Oxide Semiconductor (HV-DMOS) devices is higher than 350V. The combination of DMOS, bipolar and CMOS processing steps are compatible with dielectric insulation to provide a wide variety of MOS and bipolar devices with different voltage levels within dielectric bi-directional high voltage trench insulation on the same die.

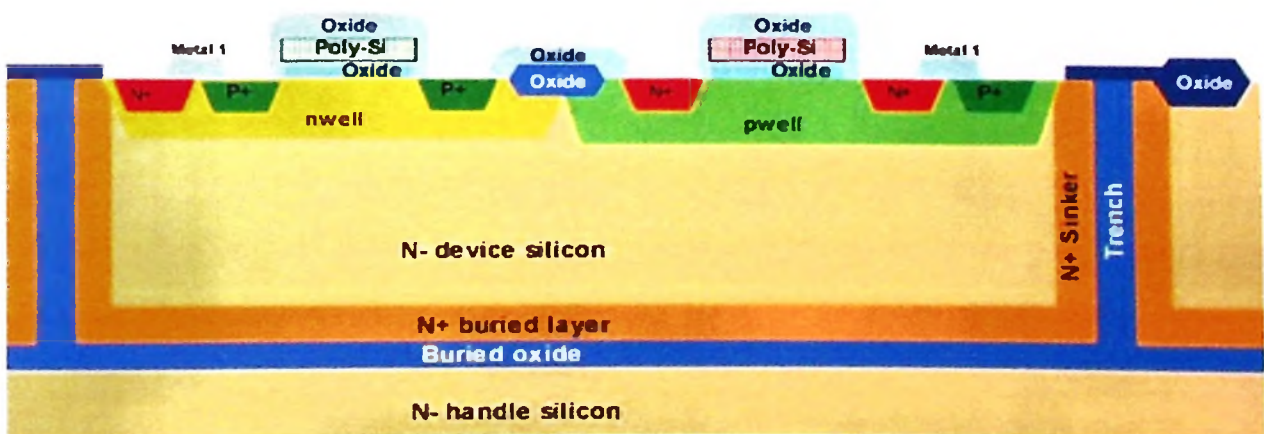


Figure 2.10: Schematic cross sections of DMOS

The 14 layers core process module provides trench insulation, single level poly with thick gate oxide, a third level metal with power metal for 350V breakdown voltage of the HV DMOS. As in Figure 2.10, an optimized self-aligned poly-gate n-channel quasi-vertical DMOS transistor and some bipolar transistors can be made with this core module. Another process modules can be added to integrate CMOS transistors, high voltage PMOS transistors, further bipolar elements and a third poly for poly-poly capacitors and high value resistors (X-FAB XDM10 Datasheet, 2009).

2.7 Summary

This chapter supports the objectives and contribution of the research. The previously proposed control circuit have issues with high voltage input and needs four switching transistor with dead-time circuit to drive the circuit compared to proposed control circuit. From the review, the behavioral modeling approach in the development of LED driver IC is a good method to integrate switching power supplies that typically comprise a complex mixed-signal system with an analog power converting stage and a digital controller. The integration of power integrated circuit for LED driver IC is the improved application in the lighting industry. Using the XDM10 process from X-FAB XDM10 Datasheet, this technology offers the integration of low and high voltage devices on the same chip.