Development of Low Power LED Driver Using LTSpice Software

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***Abstract*— LED driver is regulated power supply designed to match the characteristics of an LED or array of LEDs in our application. The LED current can vary substantially over the battery voltage range even in normal operation device, thus affect the brightness and reduce the life of the lighting device. This project present a method for the system that provides more efficient solution for driving a low power LED driver by control the LED current and to improve the usage of LEDs in good luminosity, efficiency and long life service. The current mode PWM controlled boost converter for power LEDs application is introduced. According to the characteristic of the power LEDs, they are current controlled device. Typically, the switching converters are used as the driver for power LED. For this project, the boost topology is selected as the power LEDs driver. Besides, the current mode PWM controller is used to ensure the system is stable. The project used LTC 3783 as PWM control IC and connected to driver circuit to drive low power LED. The calculations are based on design specifications. Pspice software is used for the simulation before built hardware implementation. The hardware built was tested and finally the waveform and result is recorded.**

Keywords—Low Power LED; Pspice; LTspice

I. Introduction

Currently, the advancement in the high-power LED are increasingly finding new application in emergency light, street lighting, traffic lights, automobiles, cars, flashlight and general purpose lighting. Because of their superior longevity, low maintenance requirement, improved luminance, there is no mercury inside the devices. Therefore, they perform an extremely long operating life. LEDs come in two basic categories which is Low Power LED and High Power LED. Low power LEDs commonly come in 3mm, 5mm and 8mm sizes. These are fractional wattage devices, typically 0.1 watt, operate at low current (~20mA) and low voltage (3.2 volt DC), and produce a small amount of light, perhaps two to four lumens. For high power LEDs, it commonly comes in 1-3 watt packages. They are driven at much higher current, typically 350,700 or 1000MA, and with technology can produce 40- 80 lumens per 1-watt package. High power LEDs come in many different shapes and sizes [1].

LEDs offer many advantages over traditional lighting sources. Exactly which ones are important will depend on the specific application, they include but not limited to: very long life times (50,000 hours), lower maintenance cost, more efficient than incandescent and halogen lamps, light up instantly, fully dimmable without filters, directly emit colored light without filters, complete spectrum of colors, dynamic color control tune able white point, total design freedom with hidden light, directed light for more efficient systems, vibration-proof lighting, no mercury, no IR or UV radiation in visible light [2].LEDs have many advantages such as low power consumption, high efficiency, and long life. They are not only energy efficient, but also environmentally friendly [3].

Directional light emission; LEDs are mounted on a flat surface, they emit light hemispherical, rather than spherically. For task lighting and other directional applications, this reduces wasted light. Low compact size; The small size and directional light emission of LEDs offer the potential for innovative, low-profile, compact lighting design. To produce luminance levels equivalent to high output traditional luminaries requires grouping multiple LEDs, each of which increases the heat sinking needed to maintain light output and useful life. Breakage resistance; LEDs are largely impervious to vibration because they do not have filaments or glass enclosures. LED's inherent vibration resistance may be beneficial in applications such as transportation (planes, trains, and automobiles), lighting on and near industrial equipment, elevators and escalators, and ceiling fan light kits. Instant on; LEDs come on at full brightness almost instantly, with no re-strike delay. This characteristic of LEDs is notable in vehicle brake lights, where they come on 170 to 200 milliseconds faster than standard incandescent lamps, providing an estimated 19 feet of additional stopping distance at highway speeds (65 mph). In general illumination applications, instant on can be desirable for safety and convenience.

Rapid cycling; LED life and lumen maintenance is unaffected by rapid cycling. In addition to flashing light displays, this rapid cycling capability makes LEDs well-suited to use with occupancy sensors or daylight sensors. No IR or UV emissions; HID lamps can emit significant ultraviolet radiation (UV), requiring special shielding and diffusing to avoid occupant exposure. LEDs emit virtually no IR or UV. Excessive heat (IR) from lighting presents a burn hazard to people and materials. UV is extremely damaging to artwork, artifacts, and fabrics and can cause skin and eye burns in people exposed to unshielded sources [4].

Power LEDs are current controlled devices rather than voltage. The luminous flux is determined by the forward current. As a result, the power LEDs requires a controlled output current. The conventional current control in the LED driver is using the linear regulator. In the linear regulator, bipolar junction transistor BJT will be used with the operation in active region. The load current (collector current) is controlled by the value of the base current. In order to produce a large load current, a Darlington pair BJT is used. However, the power dissipation of the BJT is very big due to high current flow. The BJT may be burnt [5].

Due to the high power loss in the BJT, it is replaced by an alternative current controller, called PWM controller. The main advantage of the PWM controller is it has better efficiency and can be widely applied to LED driver circuit. PWM controller is a control device which can be used as Voltage mode control (VMC) and Current mode control (CMC). In VMC, the control loop is set up so that the output voltage is compared to a reference voltage by an error amplifier. The output of the error amplifier equals the error. In other words, the amount of feedback voltage is away from the reference voltage. This error voltage is then compared to a wheeling saw-tooth voltage, and a PWM comparator sets the duty cycle for the power switch. The advantages of this topology are that the control loop can be made relatively fast and there is no minimum on time required. However, the disadvantage of this mode is any change in line or load must be first sensed as an output change and then corrected by the feedback loop. Normally it will take a period of time for doing the correction and hence this means slow response. Figure 1 shows the graphical presentation of the voltage mode control.

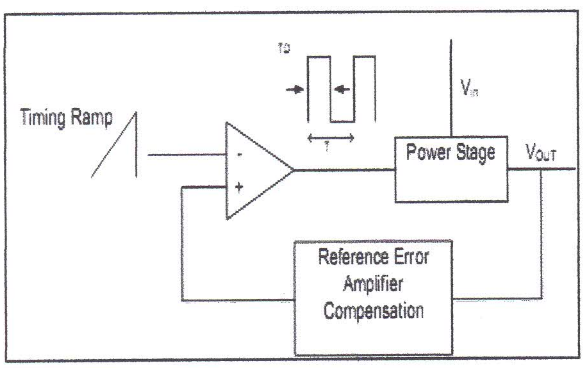

Fig. 1 Voltage Mode Control. [6]

In CMC, it is implemented through two control loops: inner loop and outer loop. Outer loop monitors the converter's output voltage. It measures the output voltage and provides an error signal to the inner loop. The inner loop monitors the inductor current information and creates the voltage-controlled current source. Inner loop compares the error signal and an analog of the inductor current to decide when to turn off the switch. The effect is to change the pulse width. The pulse width is a function of the inductor current rather than a function of the error signal. Figure 2 shows the graphical presentation of the current mode control.

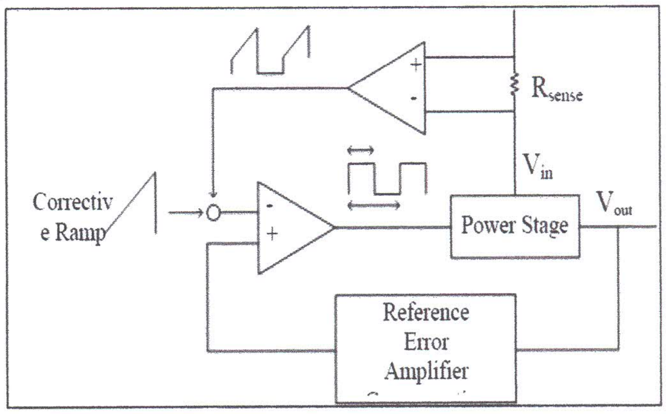

Fig. 2 Current Mode Controls. [7]

The operation of the current mode controller has advantages over a voltage mode controller. The first is that the inductor current is a direct function of the error voltage, so for small signal analysis the inductor can be replaced by a voltage controlled current source. This removes one order from the transfer function. The control loop is easier to compensate than a voltage mode circuit. Another advantage is that input line voltage changes are removed from the compensation problem. The peak current through the inductor is a function of the voltage across current to rise to the required value and for the comparator to shut off the switch [8].

In this project, boost converter is focused. Pulse width modulation (PWM) technique is to be used to control the density of the LED light in the switching converters. There is one problem faced by the current mode PWM controller. The inner current loop is unconditionally stable as long as the duty cycle is below 50%. However, the output will diverge from stable control when the inner loop is perturbed by noise or transient as the duty cycle is larger than 50%. A current mode controller can be stabilized to maintain control by adding slope compensation. The slope compensation is usually accomplished by feeding some of the voltage from the oscillator capacitor into either current sense amplifier is the error amplifier. It changes the current trip from a constant voltage to a saw-tooth waveform at the switch frequency.

II. DESIGN METHODOLOGY

In this chapter, the steps to make sure this project was done successfully will be discussed from the beginning until the project was implemented successfully. Firstly, the simulation of LED driver was done by using PSpise software. The main purpose of this result is to determine all the power components values in the boost converter power stage design. This project methodology is to increase the probability of success in hardware development and to avoid any problem from occur on hardware development. Secondly, the schematics design by refer some information from books, internet, and paper to represent the circuit of boost converter into graphic symbols. After design schematic circuit, the component that have select in the circuit need to find the value by using specific equation from previous chapter to obtain the suitable component value to be used for hardware. Finally is testing the circuit on proto-board by using several instrument and device at laboratory. Figure 3 below shows the flow of this project. Basically the steps that has been taken was divided into several parts.

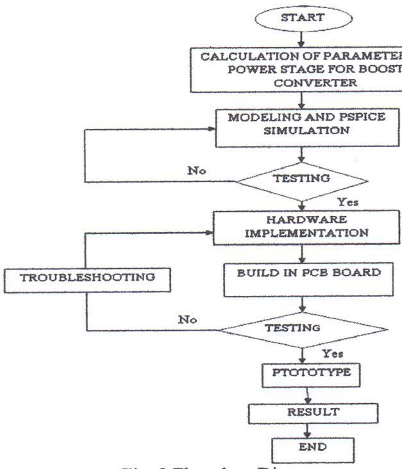

Fig. 3 Flowchart Diagram

A. *Software*

Before doing the hardware, the simulation part should be running in order to make sure that the circuit can operate correctly and achieve the purpose of the project. This part is important because by doing simulation, the fault on the circuit can be safely determine without use the real components. If any failure of the circuit operation occurs, the cause of the failure can be traced by this simulation. If the prototype is developed without doing the simulation, any failure of the circuit will cause the damage on the components. So, more budgets needed to buy the new components. By doing this simulation, the budget of the project can be minimized and components damage can be avoided.

For this project, the software that has been used:

a) PSpice - for simulation

b) LTspice – for simulation

c) Eagle – for design PCB board

After done by using PSpice simulation in Figure 4, this project continues with the LTspice simulation in Figure 5 to make sure that the circuit will operate well. For this project, it used LTC 3783 current mode PWM controller as a main controller. The result of the LTspice simulation will almost same with the PSpice simulation which by regulating the input of supply in voltage and will get the fixed of output voltage. Before plot a board, the eagle software in Figure 6 used and convert to gerber file before import the file to circuit cam to design a PCB layout by using FR4 board. This board plotted by LPKF machine in version S103.The board is plotted in single layer.

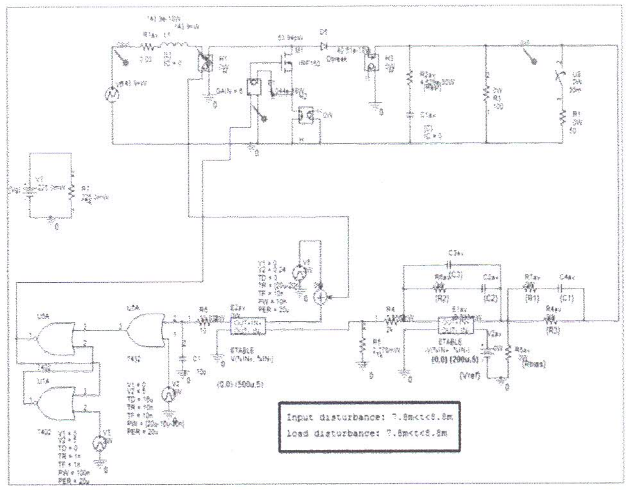

Fig .4 PSpice Simulation Circuit

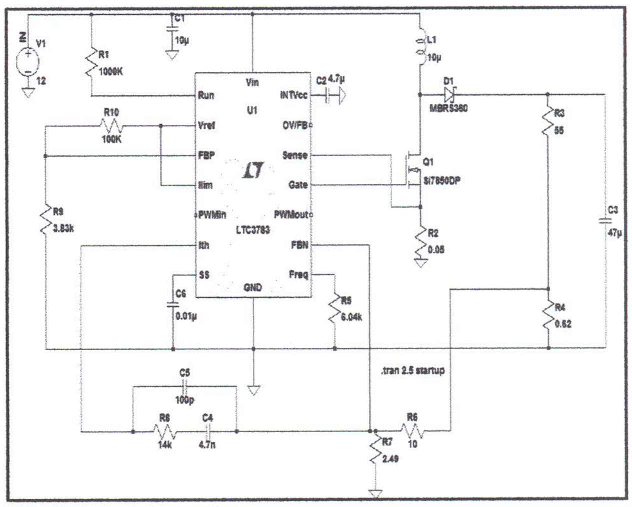

Fig. 5 LTspice Simulation Circuit

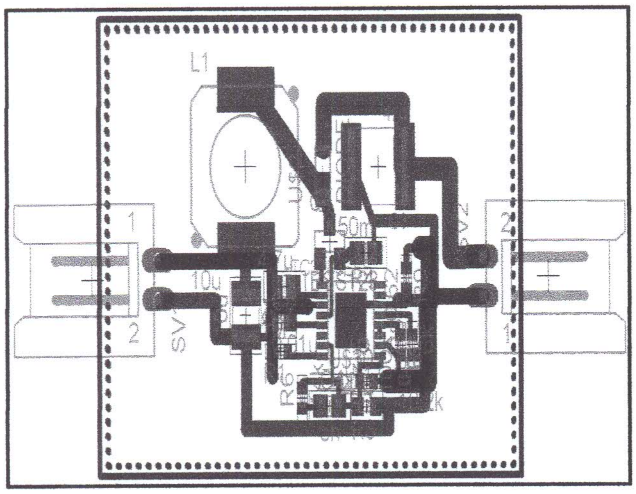

Fig. 6 Circuit Design by EAGLE

B. Hardware Implimentation

In the hardware implementation, the value of all components that are used for this project must be calculated using the formulas that already derive from basic theory of boost converter as are discussed in introduction. This LED driver circuit consists of various types of electronic components such as inductor, resistor, capacitor, and diode, MOSFET, LED and PWM as a main controller. Basic information about the component used in this circuit will be described. The component that used is an electronic device so made is called a surface-mount device (SMD). Surface mount devices (SMDs) are used in a growing number of commercial and industrial products.

Due to their small size, prototype manufacturing, rework, and repair can be difficult and are best performed using specialized techniques specific to this technology. Learning these techniques will help you succeed when working with these small components. SMDs have improved performance over through-hole components due to their smaller size, shorter internal leads, and smaller board layouts. These factors reduce the circuit's parasitic inductance and capacitance. SMDs can also be more cost effective than traditional through-hole components due to the smaller board size, fewer board layers, and fewer holes. SMDs can also be easier to replace than through-hole components on multilayer boards. This is because it is very difficult to heat the long hole on a multilayer board, but much easier to heat just the pad and component terminal of an SMD on the surface of a board.

Printed Circuit Board (PCB) is constructing for this project. The figure 7 is show the complete PCB layout circuit by using Eagle software. Then the complete PCB board is shown in figure 7 after done do all process. There are several procedures to produce the PCB which is listed below:

a) Construct and design PCB layout using Easily Applicable Graphical Layout Editor Software (EAGLE).

b) The arrangement and pad size has to be made carefully in order to prevent the short circuit at the board.

c) The complete design for circuit is converting to Gerber file.

d) LPKF machine plotter is use to making the complete circuit board.

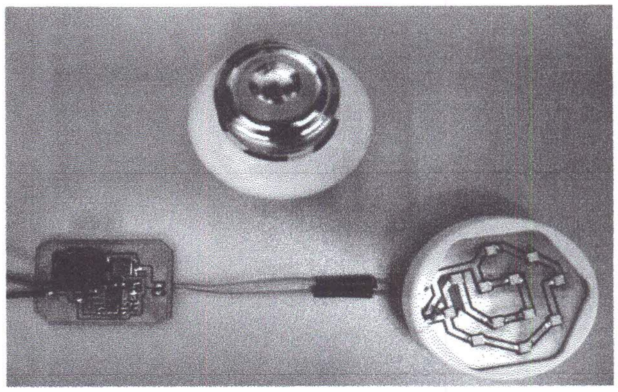

Fig. 7 Complete Circuit

III. Results And Discussion

Firstly, the input voltage is varying from 12V and 15V while switching frequency and duty cycle is set to 1MHz and 0.5. Besides that, from the calculation using the equation (2.8), the output voltage is 24V. Table I shows the specification of boost converter.

TABLE I Boost Converter Specification

Specification	Value
Input Voltage	12V
Output Voltage	24V
Switching frequency	1MHz
Duty cycle	0.5
Maximum load	400Ω
Inductor	10μH

*A. **PSpice Simulation result***

At the end of this project, the Pspice simulation will be completed and the current mode control for boost converter will be design into hardware to ensure the stability where the power converter will return to the desired operating point after some disturbances are applied. Table II show the expected result when the input voltage is varying.

TABLE II Desired Output Voltage

Input Voltage	Desired Output Voltage
12V	24 V
15 V	24 V

The simulation must be done before starting the hardware implementation since this simulation result determines input and output voltage. Duty cycle and switching frequency must be changed to 0.5 and 500 kHz. Figure 8 show results for

Pspice simulation which the input voltage is varying from 12V to 15V and output voltage is 24V and there is some ripple voltage at the output voltage. The figure 9 shows the parameter values that obtain from the simulation.

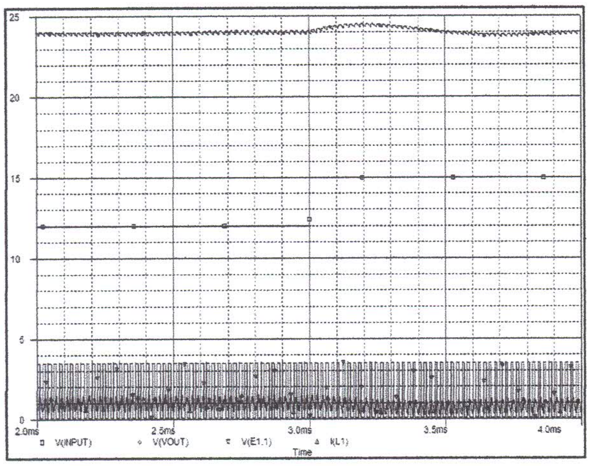

Fig. 8 PSpice Simulation Result

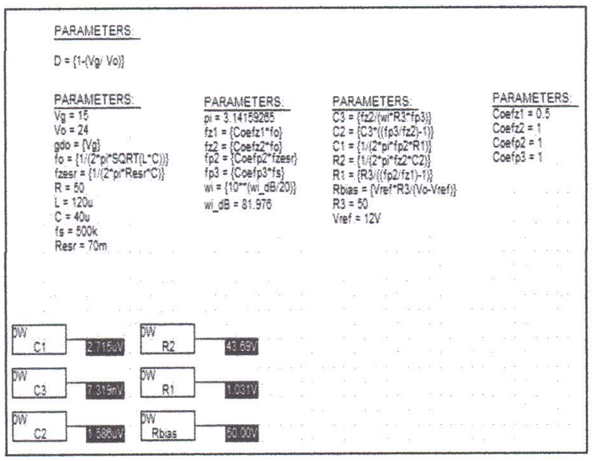

Fig. 9 Parameter Obtain From Simulation Result

The simulation part should be running in order to make sure that the circuit can operate correctly and achieve the purpose of the project. This part is important because by doing simulation, the fault on the circuit can be safely determine without use the real components. If any failure of the circuit operation occurs, the cause of the failure can be traced by this simulation. If the prototype is developed without doing the simulation, any failure of the circuit will cause the damage on the components. So, more budgets needed to buy the new components. By doing this simulation, the budget of the project can be minimized and components damage can be avoided. For a power LEDs driver, it consists of two main circuits of power stage and PWM controller. In the current mode PWM controller, the loop compensator is the important path in the PWM controller design and overall boost converter design. The loop compensator will stabilize the system when some of the parameters in the design circuit are changed. The list of parameter during PSpice simulation is show in table III.The parameter determined by using calculation and some related formula used.

TABLE III List of Parameter in PSpice Simulation

Component	Value
Inductor, L	30μH
Resistor,R1	0.1Ω
Resistor,R2	100Ω
Resistor,R3	50Ω
Resistor,R4	50Ω
Resistor,R5	39.2Ω
Resistor,R6	2kΩ
Resistor,R7	1kΩ
Capacitor,C1	33μF
Capacitor,C2	8.2nF
Capacitor,C3	1.5μF

B. LTspice Simulation result

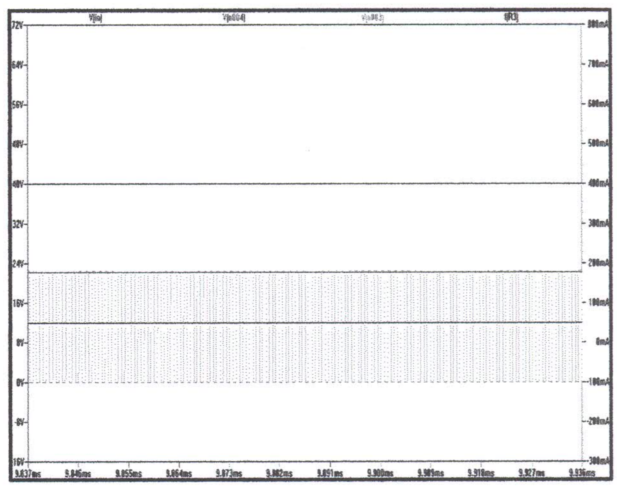

Fig. 10 LTspice Simulation

The simulation result by LTspice is determined. The parameter that have used in this simulation is used to implement into hardware. From the result that show in figure 10 have done and the output current is 0.4 A and the output voltage is 19.5 V. LTspice simulation done and the real parameter implemented into hardware. All the parameter is show in table IV.

TABLE IV List of Parameters in Hardware Design.

Component	Value
Inductor,L1	10μH
Resistor,R1	1MΩ
Resistor,R2	0.05Ω
Resistor,R3	0.62Ω
Resistor,R4	6.04kΩ
Resistor,R5	10Ω
Resistor,R6	2.49Ω
Resistor,R7	14kΩ
Resistor,R8	3.83kΩ
Resistor,R9	100kΩ
Capacitor,C1	10μF
Capacitor,C2	4.7μF
Capacitor,C3	47μF
Capacitor,C4	4.7nF
Capacitor,C5	100pF
Capacitor,C6	0.01μF

C. *Hardware Result*

By using oscilloscope

The hardware circuit is used to measure the efficiency and power loss on the circuit. The value of frequency in the PWM circuit is 965.3 kHz and the duty cycle is 0.5 as the value in calculation to obtain the equal output voltage which is 24V. Figure 11 show input voltage is equal to 8V and figure 12 show the output voltage is equal to 19.5 V and output current is equal to 0.4A.

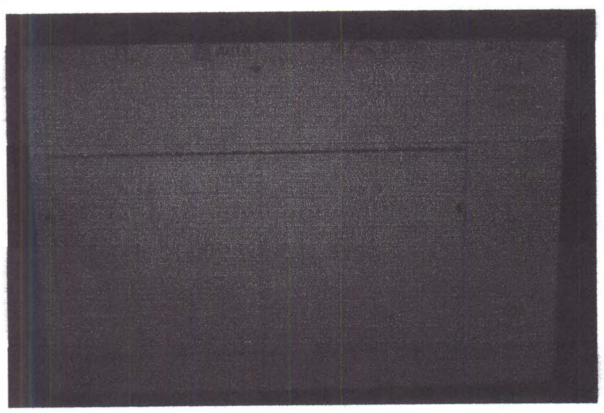

Fig. 11 Input Voltage

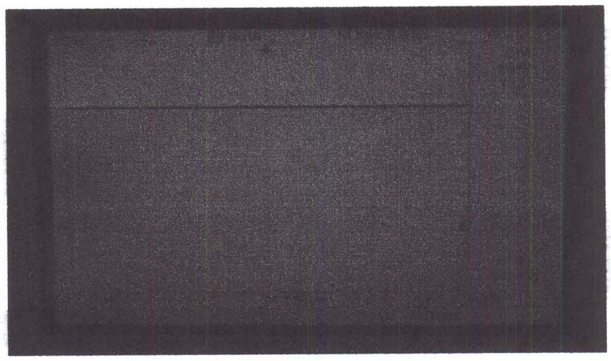

Fig. 12 Output Voltage

By using oscilloscope, Figure 13 shows duty cycle waveform, frequency is remain constant between 965 kHz to 966 kHz. Figure 13 show the output of PWM with duty cycle is equal to 0.5, input voltage is 8V, the output voltage is 19.5V and the frequency is 965.3 kHz.

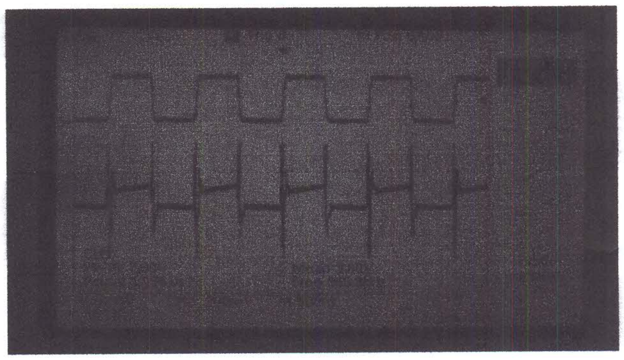

Fig. 13 Output of PWM With Duty Cycle

By using multimeter

The output voltage is 19.5V from the 8V input voltage and the output current that have measured by multimeter is 0.4 A. There are some losses occur during troubleshooting. The required current that should drive a power LED is about 0.4A which is 0.2 for each series. The typical current is selected for make sure that the temperature is suitable for making a long life service. The output current and hardware design is show in figure 14.

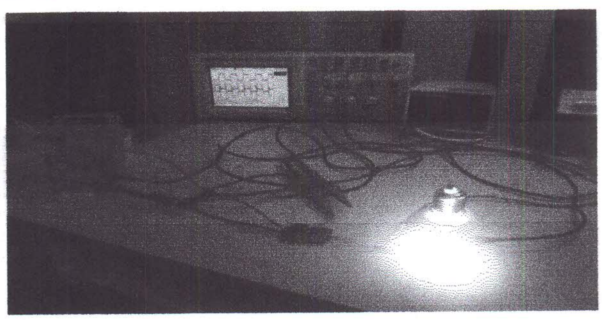

Fig. 14 Hardware Testing

IV. Conclusion

Pspice and LTspice software are used widely in investigating and design project for boost converter in order to determine if the circuit meets the design criteria. In the current mode PWM controller, the loop compensator is the important path in the PWM controller design and overall boost converter design. The loop compensator will stabilize the system when some of the parameters in the design circuit are changed since the simulation of Current Mode Control for Boost Converter well done by using Pspice and LTspice during this project. In this project, a current mode PWM controlled boost converter is made for the power LEDs application. The design example can be used as a guide in order to build a real hardware design. For a power LEDs driver, it consists of two main circuits which are power stage and PWM controller. For the low voltage application, the boost topology is selected as the driver. There are two modes of control in the PWM controller. Voltage mode control and Current mode control. Due to the more advantages of the current mode control, a current mode PWM controller is designed by using LTspice software.

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