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# Smart intelligent control of current source for high power LED diodes

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ABSTRACT

Current trends in low power electronics represent e.g. low power lightings, where classical light bulbs are replaced by halogen or Light Emitting Diodes (LED) lights. In the context of the development of saver LEDs the manufacturing technology is overcoming the borders which results in the production of High Power (HP) LEDs at the opposite side of the spectrum. One HP-LED with 100 W power is available in current China markets. However, such a great power needs a new access to control the current source. The main problem is overheating which leads to lowering of HP-LEDs lifetime or, in an extreme case, destroying lightings. Our paper deals with an intelligent solution which solves all the problems of current source design and control. The developed solution is also prepared for remote control of power.


## 1. Introduction

The deployment trend in current electronics leads mainly to the development of low power and miniaturized solutions which are intelligent and connectable with other devices e.g. consumer electronics or Smart Homes [4,21]. On the other hand there is a possibility to use miniaturized high power lightings in sense of Light Emitting Diodes (LEDs) due to the high efficiency of these elements. These High Power (HP)-LEDs are more suitable for energy saving applications, within which they replace traditional fluorescent and incandescent bulbs due to their high energy efficiency.

Some of the specialized China based markets (Hong-Kong manufacturers) sell HP-LEDs with one LED diode unit of 50 or 100 W power (Fig. 1). However, such a great power needs a new access to control current source in contrast to classical low power LEDs. The main problem is overheating which leads to lowering of LEDs lifetime or in an extreme case destroying lightings [1]. The temperature also strongly influences the properties of LEDs [2]. The mentioned paper solves the overheating problem by adding a flat heat pipe which compensates 3 W LED at 52 °C. However, the presented solution is not suitable for HP-LEDs with 10 times higher power delivering more than 50 or 100 W. An interesting study, focused on the effect of light output on the total thermal resistance, was performed by Anithambigai et al. [3]. The authors conclude by giving the results that the efficiency and the reliability of LEDs are strongly dependent on the optical properties of the device. Taking into account the special reliable studies of illumination distributions of LEDs, it is still impossible to design and develop a solution for integrated HP-LED with optimal illumination distributions alongside the traditional access to current source design (including the earlier-used power sources).

There are also many new trends in sense of Smart Homes and Smart Things interconnection and popularity of new Smart Solutions (e.g. Smart Thermostats [5]) which allow controlling using Smart Phones, iPADs, or other computer devices [22]. All these trends need to be taken into account when a complex solution is designed.

The rest of our paper will focus on real usage of HP-LEDs in real environments as well as on the needs of current trends of Smart Solutions. We will describe our smart intelligent solution which solves all the problems of current source design and control. The developed solution is also designed for remote control of power and use of Real Time Clock (RTC [6,18,27]) to predefine a variable power emission per day. The presented solution is suitable for indoor as well as outdoor usage due to the compact size of its control unit.

The tested high-power LED modules are presented in Fig. 1. There are two 50 W LEDs with a working voltage of about 35 V and a passing current of 1.5 A at maximum. A massive heat sink with forced convection is absolutely mandatory, because of the high heat dissipating from LEDs. This arrangement was set up to test high power LEDs and DC/DC converter. LEDs were provided by Seoul Semiconductor manufacturer and are relatively common.

## 2. Related commercial solutions for HP-LEDs powering

The expansion of the use of HP-LEDs in every environment is nowadays enormous; however the companies' focus on the intelligent powering of these HP-LEDs is not the same. HP-LEDs

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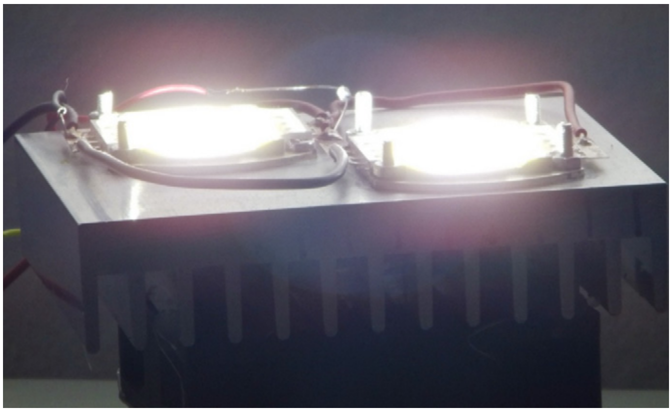

**Fig. 1.** Two HP LEDs (2 × 50 W) with cooler.

**Table 1**
Comparison of existing HP-LED power sources.

| Company | Price (USD) | Weight (kg) | Remote control | Adaptive lighing |
|---|---|---|---|---|
| LedFox GmbH [34] | 128 | – | No | No |
| LCK LED LIGHTING CO. LTD. [35] | 65 | 1.4 | No | No |
| Expected solution | Max. 30 | Max. 0.3 | Yes | Yes |

are in the market for the past couple of years, but the circuits for their control are slowly coming now. Most of the manufacturers focus on LED sources for LCD displays. The first suitable solution for HP-LEDs was NCP3066 circuit designed by ON Semiconductor Company. It has the option of sleep mode by logic signal, current feedback and integrated switch of bipolar type. The option of PWM signal with stabilized output current is also an advantage. The driving efficiency is around 80%. However, the maximal output is only 4 W.

Only very expensive circuits and solutions exist for powering HP-LEDs with more than 100 W that can be ordered from the manufacturers (Table 1). Size of these solutions is also unusable for most cases (e.g. street lighting, tiny ambient illumination).

Some of the mentioned power sources have an external control of MOSFET transistors due to the impossibility of implementation of switching elements designed for currents over 10 A (e.g. for power losses). The external switching elements are suitable for very low resistance when they are on-state (commonly 1 mΩ with power losses of 0.1 W). Another modern component, which is implemented, is synchronous rectifier. The unsuitable Schottky diode (power losses are 7 W for 10 A) is substituted by N-MOS elements, which cut power losses to minimum. However, this modern solution has several disadvantages:

- Implementation of synchronous rectifier is difficult.
- Used transistors need voltage of 8 V higher than the supply voltage. To solve this it is necessary to implement a charge pump.
- Due to these added changes a complexity of PCB design grows up, which is why these types of converters are not common.

The fundamental advantage is, however, the highest efficiency of 97%. This is very important for sources with such a high output power (100 W or more), where in case of 80% efficiency a power loss results in 20 W. Such high values have influence on other PCB components and their parameters for warming up.

Our solution comes from the basic driving circuit NCP3066 designed by ON Semiconductor. This device has an integrated bipolar transistor, which can switch 1.5 A at maximum. This device is intended to power low-power LEDs, but its simplicity and verified functionality is useful when designing high-power current controllers for big size LEDs. Its main disadvantage is inner switching component. The bipolar switching device itself is not suitable for DC/DC converter because of the high $U_{CE}$ voltage. This voltage drop creates a significant source of heat and strongly decreases overall efficiency. This device is controlled by the current passing through the base input, making the switching very fast and as a whole, making it look like a resistive load. The goal was to replace the inner bipolar device by external, high-power, low $R_{DS\text{-}ON}$ unipolar device. This is very easy, because similar components can be bought relatively cheaply (for example HEXFET IRFH8311 with On resistance about 0.002 Ω). This replacement is not that easy because the driving MOSFETs is slightly different than the driving bipolar device. We have to obtain high voltage and high slope signal. High driving voltage is a relative term. Bipolar device can handle driving voltage with an amplitude of 0.7 V. HEXFET unipolar device needs driving voltage of about 4–5 V. Higher voltages are better from On resistance point of view, but this leads to increasing the switching losses (not proportionally, but exponentially). Therefore, the operation frequency and gate charge is the key to good efficiency design.

The losses on switching element can be described as follows. The first loss type is heat originating on internal resistance, when the transistor is switched on.

The driving circuit supplied by On Semiconductor has originally only 4 W of output power. This circuit is intended to drive medium power LEDs in flashlights or in handheld devices. However, this driver is very easy to assemble, needs minimum external components and if we observe some general requirements, we can extend the driving power to tens or hundreds of watts. After conducting some tests and modifications, we are now able to drive even 100 W LED with external switching device. The main modification is external switching MOSFET transistor. This is the most important improvement. NCP3066 acts only as a LED current analyzer and a driver of this MOSFET transistor. MOSFET devices are known for a long time. However, recently the technology advanced further in this area and the switching parameters of these transistors became superior. $R_{DS\text{-}ON}$ (On State Resistance) value decreases under 10 mΩ and values around 1 mΩ are not rare. Gate charge drops below 10 nC and $V_{GS}$ voltage sinks under 4 V. Together these attributes allow building DC/DC converters of previously untouchable efficiencies and sizes. With the driver support, reactions on input change are under 200 ns, allowing the output capacitors to be smaller. This leads to usage of ceramic capacitors, which have smaller capacitances, but have much smaller internal resistance ($E_{SR}$). This results in smaller heat dissipation and lower output voltage and current swing. These circumstances led us to use NCP3066 driver circuit and the modern external MOSFET transistor (IRF1404).

## 3. High power problem issues

Based on aforesaid, an efficient and cheap control of HP-LEDs (100 W or more) with mentioned advantages needs to be added and some components which increase the complexity of the final regulator circuit needs to be dropped out. As an ideal variant, we consider, a combination of a single chip Micro Controller Unit (MCU) together with a reliable functionality of the standard LED regulators. One such example is NCP3066 circuit which we implemented in our solution. Regarding the current limitations of available regulation circuits, an external switching element