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Solar LED Lamp Application Using the CAT4139

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APPLICATION NOTE

INTRODUCTION

Our age, characterized by the high degree of global industrialization, environmental pollutions and energy shortages, requires developing renewable energy sources. In a variety of renewable energies, solar energy is one of the most attractive selections together with high power light−emitting diodes (LED). LED lighting for the future development is the trend, which has several advantages, such as low power consumption, long life, fast response and small size. The combination of solar power, used to recharge batteries, and LED light sources that require only a fraction of the electricity to provide the same amount of light as traditional incandescent bulbs. This means that solar LED lights should be considered in all applications where energy savings and the environment quality are a concern.

This application note describes implementation of the CAT4139, a dc−dc step−up converter that delivers an accurate constant current for driving serial LED string. A prototype solar module (Figure 1), based on commercial mono−crystalline silicon solar cells [1], recharges one Li−Ion battery cell (TrustFire 18650) to drive two white LEDs (Osram APT+ [2]) connected in series.

SOLAR ENERGY

Solar energy is a solution for the depletion of conventional fossil fuel energy sources and serious environmental problems has been attracting around the world. Photovoltaic systems (PV) are converting solar energy into electrical power, which is nowadays widely used.

The photovoltaic field has given rise to a global industry capable of producing many gigawatts (GW) of additional installed capacity per year. Photovoltaic market installations reached a record high of 7.3 GW in 2009, representing growth of 20% over the previous year. The PV industry generated $38.5 billion revenues in 2009 worldwide, while successfully rising over $13.5 billion in equity and debt, up 8% on the prior year [3].

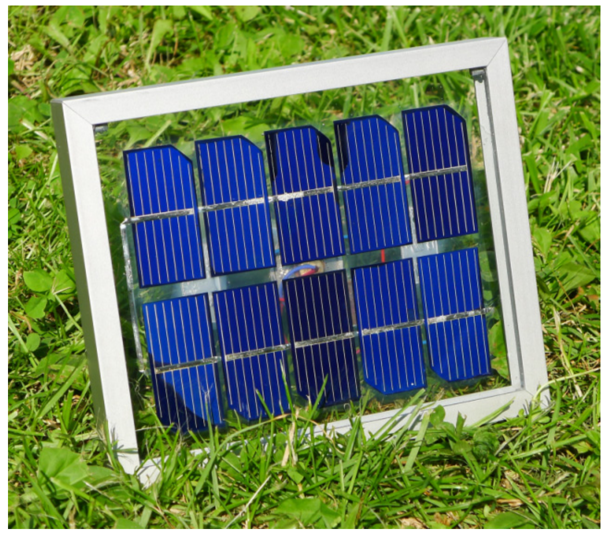

Figure 1. Solar Module Prototype

SOLAR CELL

Basic unit for conversion of solar energy to electrical is solar cell, usually based on mono−crystalline silicon incorporating a pn−junction. A built−in interior electric field around this p−n junction separates the charge carriers created by illumination. Thus electrical power is generated at solar cell output. Under the illumination of the sun (~1000 W/m^2), basic solar cell unit generates a dc photo−voltage from 0.5 V to 1 V, depending on material properties, temperature. In short circuit, a photocurrent with several tens of milliampers per cm^2 is generated. This means higher cell area produces higher currents from the cell. Although the current is reasonable, the voltage is too small for most applications. To produce useful dc voltages, the cells are usually connected together in series and encapsulated into a solar module. In this application solar module needs to have output voltage above 5 V with reasonable current output capability, required by Li−Ion accumulator (Figure 2).

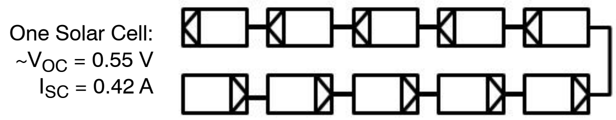

Figure 2. Block Structure of an Experimental Photovoltaic Module – 10 Cells Connected in Series; Solar Cell Characterization at Standard Test Conditions (STC) [4]: V_{OC} = 0.55 V, I_{SC} = 0.42 A, Active Area 5 x 2.5 cm

BOOST DRIVER

For compact lighting applications like solar lamps, layout area is an important factor. The goal is to supply constant current to LED string independent on Li–Ion battery voltage, that varies during discharge. To create such application, an accurate constant current LED driver CAT4139 was chosen. This dc–dc step–up converter operates at a fixed switching frequency of 1 MHz allowing the device to be used with small value external ceramic capacitors and inductor. The CAT4139 [5], boost topology is illustrated in Figure 3.

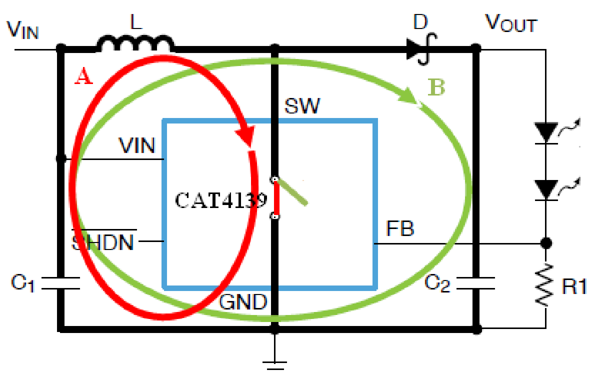

Figure 3. Open and Closed CAT4139 Internal Switch Behavior

The device uses a high–voltage CMOS power switch between the SW pin and ground to energize the inductor. When the switch is turned on, energy flows into the inductor (case A). When the switch is turned off (case B), the stored energy in the inductor is released into the C2 and load via the Schottky diode (D). The on/off duty cycle of the power switch is internally adjusted and controlled to maintain a constant regulated voltage of 0.3 V across the feedback resistor (R1) connected to the feedback pin (FB). The value of the resistor sets the LED current accordingly (0.3 V/R1). The SHDN pin enables the CAT4139, typically at 0.8 V or above and disables the device at a voltage lower than 0.7 V. This functionality is used to control ambient illumination level thus controlling LED light output. Please refer to Section Practical Realization for detailed operation.

LI–ION BATTERY CELL

In this application, Li–Ion battery cell (TrustFire 18650) is used to store electrical energy coming from photovoltaic module described above. The choice of battery type resulted from many advantages of Li–Ion technology over other battery types. Li–Ion is a low maintenance battery with no memory effect. Scheduled cycling is not required to prolong the battery's life. In addition, the self–discharge is less than half compared to nickel–cadmium. An important aspect is the energy density of Li–Ion is typically twice that of the standard nickel–cadmium. Nickel–based pack would require three 1.2 V cells connected in series to replace one Li–Ion cell of 3.6 V. Each 1.2 cell has different properties therefore to keep optimal performance balancing circuitry would be necessary.

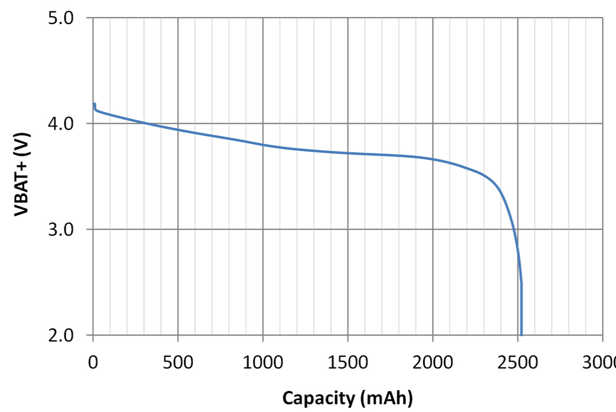

Figure 4. TrustFire 18650 Discharge Curve at Load of 0.25 A (Full Discharge Time 10h)

Used TrustFire 18650 has built in protection circuit to maintain safe battery operation. This circuit is designed to disconnect the cell either at overcharge current/voltage (2.4 A / 4.2 V max) or discharge current/voltage (3.6 A/2.8 V) [6]. The discharge curve at load of 0.25 A is shown in Figure 4, where it can be seen that voltage decreases with discharge time across battery cell. CAT4139 compensates battery voltage variation and keep constant current supplied to LED string.

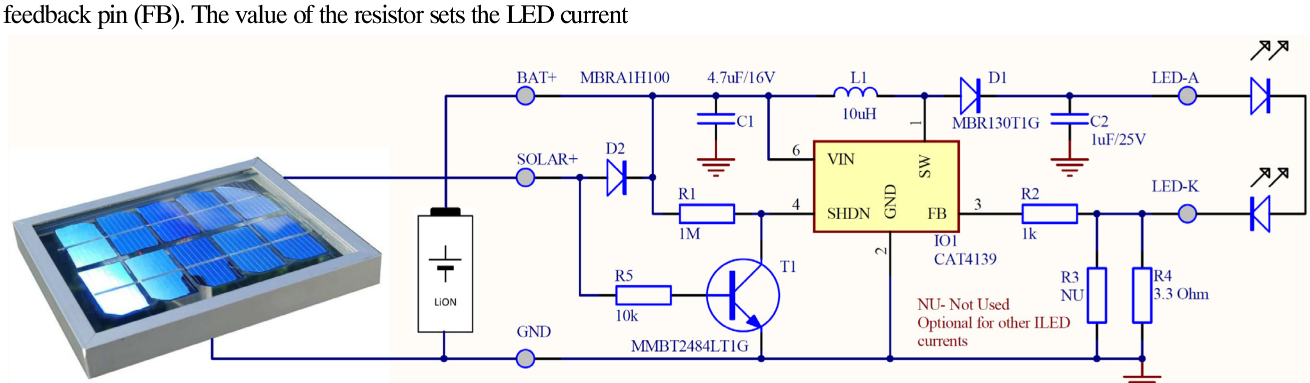

Figure 5. CAT4139 Solar LED Lamp Schematic

PRACTICAL REALIZATION

Solar lamp consists of three main parts; solar module, Li−Ion battery described above and constant current driver based on the CAT4139. Schematic of the driver is shown in Figure 5 and operation is described in Section Boost Driver.

Battery cell is charged during daylight, when average voltage on solar module (SOLAR+ pin) is around 4.2 V. Charge current at solar module output varies proportionally to incident light and charging is controlled by incorporated protection battery circuit. SOLAR+ voltage switches on transistor T1 and its collector voltage disables the CAT4139. When ambient light is decreased and voltage on SOLAR+ pin is below threshold given by base−emitter voltage of T1, the CAT4139 driver is enabled and supplies constant current to LED string (T1, R5, R1 circuit is used to invert voltage coming from solar module.). During night, battery is being discharged. D2 is used to prevent from reverse current flow from battery to solar module. The constant LED current is given by value of R4 resistor (in this case, 0.3 V/3.3 Ω = 0.091 A).

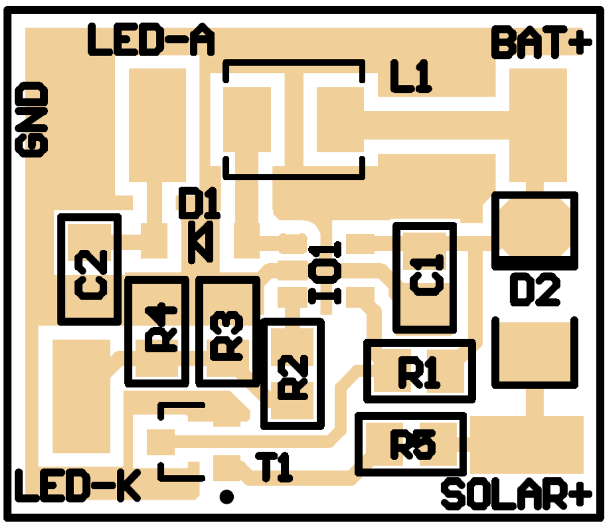

Figure 6. PCB Assembly, TOP Layer View, Board Size 21 x 18 mm

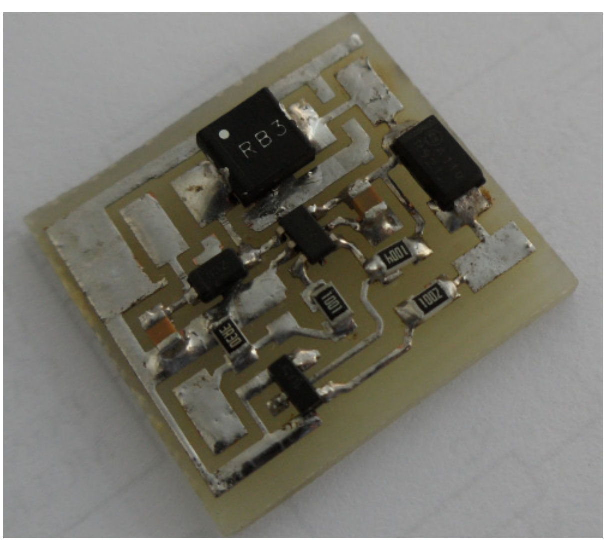

Figure 7. Assembled PCB, TOP Layer View

CAT4139 was assembled on FR4 PCB board shown in Figure 6, following recommendations from the product datasheet [5]. Practical realization is shown in Figure 7 for PCB and Figure 8 for assembled solar lamp from back side. Solar module, PCB and LEDs were encapsulated between two glass sheets. Surrounding aluminum profiles hermetically sealed inner volume of the solar lamp. Aluminum stick in the middle of the bottom glass plate includes single cell Li−Ion battery.

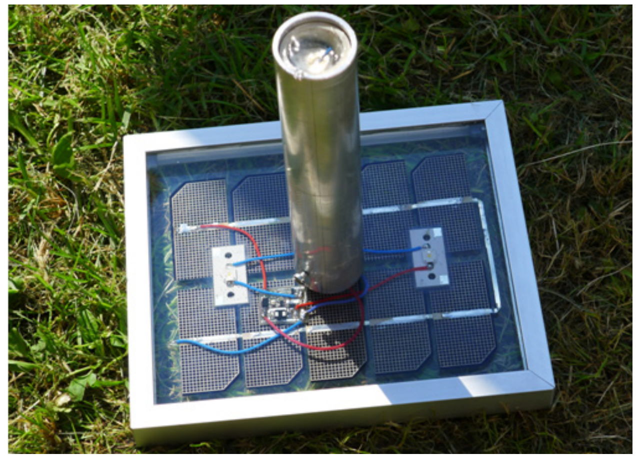

Figure 8. Backside of Realized Solar LED Lamp

Realized driver resulted in efficiencies from 75 up to 86%, for 10 μH inductance (recommended value), depending on battery voltage as shown in Figure 9.

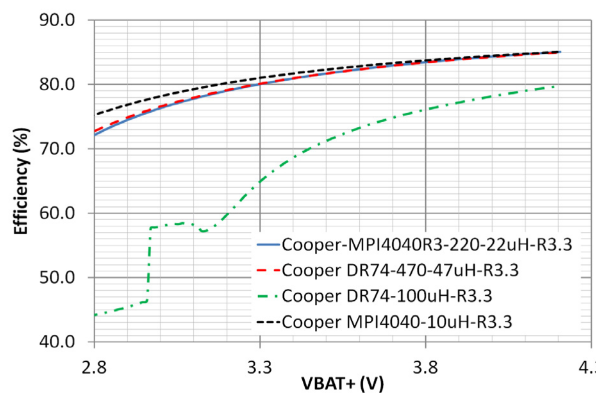

Figure 9. CAT4139 Efficiency Changes with Battery Voltage

Conclusion

The goal of this work was to create most efficient constant current boost driver operational from single cell Li−Ion battery recharged from solar module.

Solar LED lamp prototype was exposed to outdoor conditions for a few days during summer season (Europe climate, Piestany, Slovakia). Measured results are shown in Figure 10 for current and Figure 11 for voltage variations.

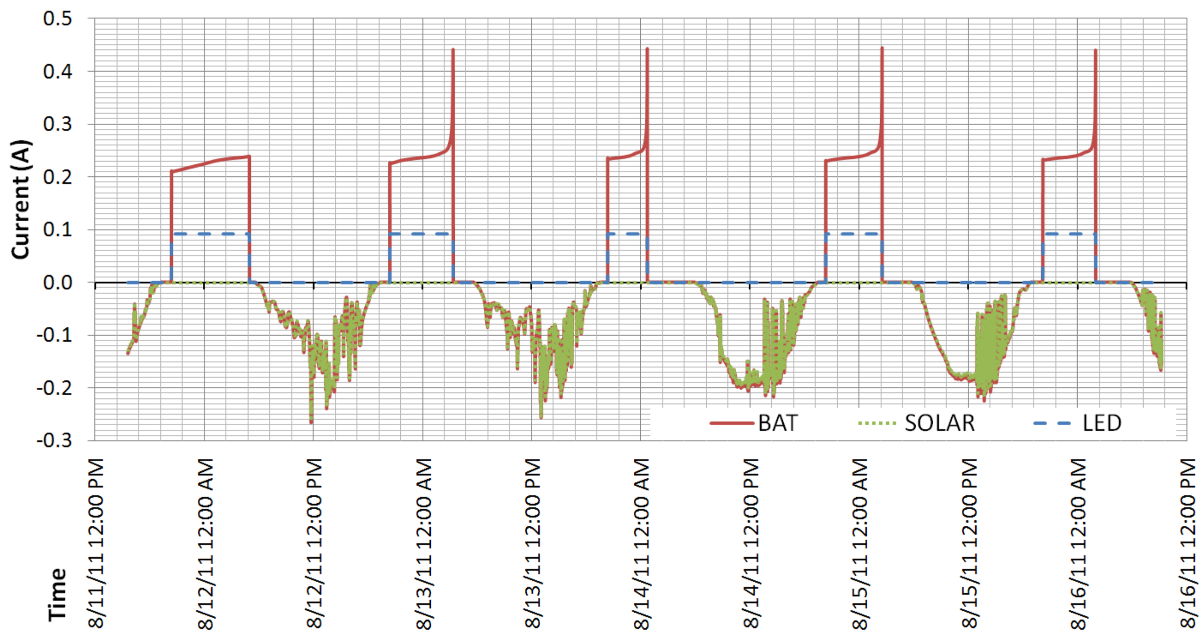

Figure 10. Current Variation in Outdoor Environment

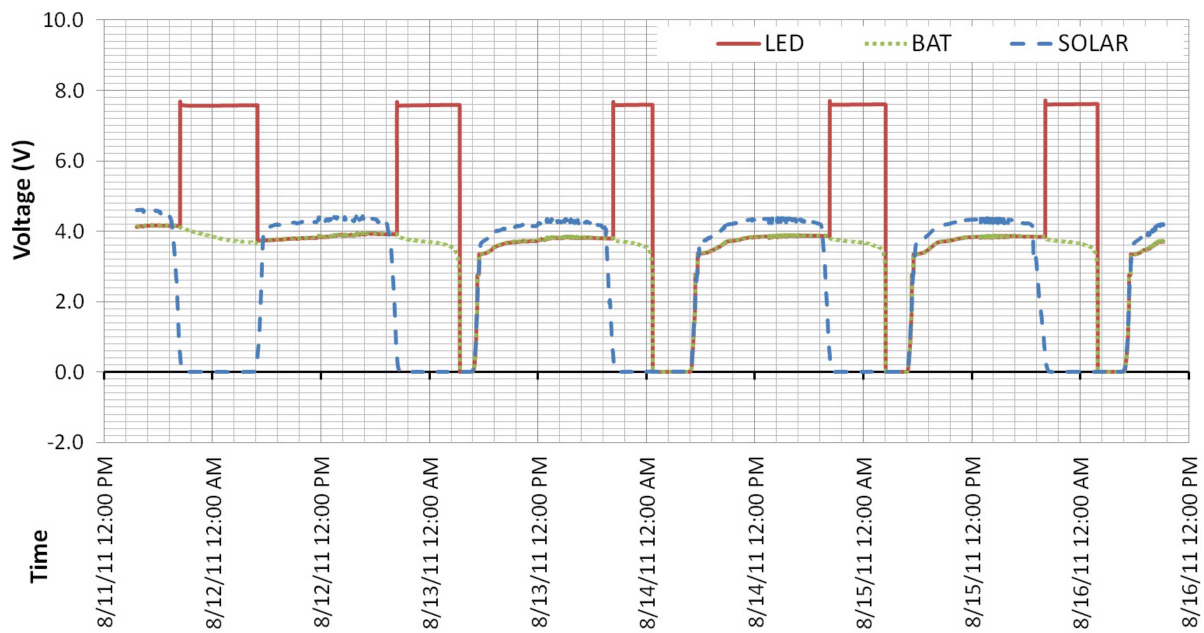

Figure 11. Voltage Variation in Outdoor Environment

As can be seen from these charts, first day LED string was powered from fully charged battery and covered whole night operation. Depending on daily illumination level, battery was charged differently in following days as can be seen as different discharge battery times during the night. For instance next two days were cloudy with large variation of charging current from solar module (“SOLAR” from Figure 10). You can see that LED current was constant during whole operational time. Please notice that used solar module was not able to fully recharge battery for each day. Thus, the area of the solar module needs to be extended if there is a requirement to operate the LED string all night long for each day. Such application can be utilized for autonomous illumination, garden lamps, orientation illumination, emergency lighting, road markers and many others. For applications requiring more than five LEDs, CAT4240 is recommended instead of CAT4139.

Table 1. CAT4139 PCB BOARD LIST OF COMPONENTS

Name	Manufacturer	Description	Package	Part Number	Quantity
C1	AVX	Ceramic Capacitor 4.7 μF/16V	0805	0805YD475KAT	1
C2	AVX	Ceramic Capacitor 1 μF/25 V	0805	08053D105KAT	1
D1	ON Semiconductor	Schottky Rectifier 1 A, 30 V	SMB	MBR130T1G	1
D2	ON Semiconductor	Schottky Power Rectifier 1 A, 100 V	SMA	MBRA1H100T3G	1
IO1	ON Semiconductor	350 mA Step−Up Switching Regulator	TSOT−23−5	CAT4139TD−GT3	1
L1	Cooper Bussmann	Miniature Power Inductors 10 μH	SMD	MPI4040R3−100−R	1
R1	Yageo	SMD Resistor RC0805 1/8 W	Size 0805	1M	1
R2	Yageo	SMD Resistor RC0805 1/8 W	Size 0805	1k	1
R3	Yageo	SMD Resistor RC0805 1/8 W	Size 0805	Not Used	1
R4	Yageo	SMD Resistor RC0805 1/8 W	Size 0805	3.3 Ω	1
R5	Yageo	SMD Resistor RC0805 1/8 W	Size 0805	10k	1
T1	ON Semiconductor	NPN Bipolar Transistor, 60 V, 0.1 A	SOT−23−3	MMBT2484LT1G	1

Reference:

1. Solartec s.r.o.: http://www.solartec.cz
2. Osram APT+ specification: http://www.osram−os.com/osram_os/EN/
3. S. Rustemli, F. Dincer: ”Modeling of Photovoltaic Panel and Examining Effects of Temperature in Matlab/Simulin”, ELECTRONICS AND ELECTRICAL ENGINEERING, 2011. No. 3(109), ISSN: 1392−1215
4. IEC international standard 61215: Crystalline silicon terrestrial photovoltaic (PV) modules − Design qualification and type approval, Geneva, Switzerland, 1993
5. CAT4139 datasheet: http://www.onsemi.com/pub_link/Collateral/CAT4139−D.PDF
6. TrustFire 18650 detailed product specification: http://trustfire.en.alibaba.com/product/231676984−200513194/rechargeable_battery.html

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