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The Design of the Drive Control Chip for the Solar LED Lighting System

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Abstract

Combining with the application characteristic of solar energy system and the drive characteristic of high-power lighting LED, in this article, we develop a sort of new drive control chip of solar LED lighting system, which not only can be drove by the invariable current of 350mA, but also can realize functions including the regulation of charger and discharge, preventing reverse charge, preventing over charge, preventing over discharge, and preventing reverse connection of the storage battery in the photovoltaic system.

Keywords: Solar energy, High-power LED, Controller

1. Introduction

Light-emitting diode (LED) is a sort of semiconductor emitting apparatus which can translate the electric energy into the visible light and possess advantages such as saving energy, environmental protection, long life and free maintenance. The solar LED lighting is the combination which utilizes the solar battery to offer of electrical source and uses LED as the lamp-house, and the solar battery is directly translate the light energy into the DC electrical energy, and the subassembly of the solar battery can be assembled at will through the series-wound or shunt-wound fashion to obtain the voltage actually needed. These characteristics are just matched with LED and can not be achieved by traditional power supply system (Chen, 2006). If the solar battery is combined with LED, the AC and DC will be translated directly and need not any reverse equipment, so the solar LED lighting system will obtain high energy utilization ratio, which possesses characteristics of safe, environment protection, and zero energy consumption, and is real green lighting system.

In the solar LED lighting system, the drive control circuit is the most important part, which is the key to differ with usual light system, which design is directly relative with the function and reliability of the system, and decides the operation of the system. At present, most solar control circuits are composed by analog electronic circuit, and because of its reliable and mature technology, so its application is very broad. However, this sort of controller is made by independent components which possess characteristics including numerous quantities, low integration degree, large volume and serious power consumption, and the constant voltage signal of output controlled by it is not fit for the drive use for high-power LED.

Therefore, it is necessary to integrate independent components on one piece of silicon wafer, and the solar LED drive control chip and its application circuit which possesses perfect design functions and simple structure can drive high-power LED through the constant current and have the function of usual solar controller. It can not only fulfill the actual requirement of the solar LED lighting system, but also enhance the reliability, reduce power consumption and decrease the volume. Accordingly, it establishes stable base for the popularization and application of the solar LED lighting technology.

2. System composing and function requirement

In the solar LED lighting system, the solar panel is necessary, which is the apparatus translating solar energy into the electrical energy. Because of the covering of clouds, the output of solar energy on the ground is intermittent and can not be forecasted, so some energy system which usually is the storage battery must be founded in the system. To prolong the use life of the storage battery and fully utilize the solar energy, the most important apparatus in the solar LED system are the drive control circuit and the lighting lamp-house LED lamp because of the characteristic of LED. Above four parts compose the solar LED lighting system which is seen in Figure 1. Because this system adopts the DC load (according the characteristic curve of LED, the constant current source is generally used), so the reverse regulation equipment which translates DC into AC doesn’t need in the general solar system. The work principle of the system includes that at day, the solar panels stores the electrical energy obtained from solar radiation in the storage battery, and at night, the storage battery supplies powers to the lighting LED lamps and lanterns, illumines the lamp-house, roads or squares. The drive control circuit is the “brain” of the whole system which controls the solar battery, the storage battery and LED lamp to operate conformably.

The functions of the drive control chip of the solar LED lighting system and the application circuit mainly include following aspects.

(1) It can export the constant current of 350mA±5% to the high-power LED, and the current can be regulated by the external resistors Rxt, and the current doesn't change with the change of the voltage or the environmental temperature of the storage battery.

(2) It can turn on the LED lamp at dark and turn off the LED lamp and charge to the storage battery automatically at day. The symbol voltage when the LED lamp turns on is 1.5V.

(3) It can offer the storage battery functions of charge and discharge regulation, preventing reverse charge, preventing over charge, preventing over discharge and preventing reverse connection. The symbol voltage when the storage battery ends discharge and the symbol voltage when the storage battery ends charge are all 3.3V.

(4) It can offer the protection of preventing reverse connection for the solar battery.

3. Circuit structure and work principle

The LED constant current drive part of the chip adopts the mode of linear series-wound control which has good constant current precision, low ripple current, high reliability without any electromagnetic interference. The charge and discharge control part of the solar LED lighting system adopts the single path and bypass charge and discharge controller frame (Zhao, 2004), takes the voltage comparator composed by operational amplified circuits as the control circuit, and sets up the control state of the system through the regulation of the potentiometer. The chip principle structure and the application circuit are respectively seen in Figure 2 and Figure 3.

The chip power is offered by the storage battery which exports 12V DC voltage that is reduced to 5V through the voltage regulator Z1, and the whole circuit is composed by following modules, one high-power NMOS pipe MSG which is connected by 755 NMOS pipes with the ratio of width and length of 10μm/1μm and can offer the drive current of 350mA, one sensor NMOS pipe M5 with the ratio of width and length of 10μm/1μm which uses grid and source together with high-power MSG, one reference voltage source BG which can produce constant voltages 3.3V and 1.5V that can not change with changes of voltage and temperature of the electrical source, one error operation amplifier YF, three buffers HC which are used to isolate the influence of the latter class and increase the output drive ability, LED switch circuit KG which can control charge and discharge of the solar LED system, and various protective circuits. Those apparatus which adopt exterior connection include sampling resistance Rxt, potentiometer Rwskg, Rwbgc and Rwbgf, protective Schottky diode SBD1 and SBD2, protective rectifier diode D1, high-power NMOS switch pipe M0, fuse pipe FUSE1, shunt capacitance C1 and protective capacitance C2, voltage regulator Z1 and resistance R1.

The work principle of the whole circuit includes two parts.

(1) The work principle of LED constant drive part.

The reference voltage source BG produces two reference voltages, 3.3V and 1.5V, where, the reference voltage of 1.5V is exported from the buffer HC and enters into the reverse port of the error operation amplifier WCYF which output controls the grid voltage of the power NMOS pipe MSG and sensor NMOS pipe M5 and makes it fix at 1.8V, and accordingly the corresponding drive current is obtained. The sensor current produces sampling voltage on the sampling resistance Rxt, and the difference between the reference voltage of 3.3V and this sampling voltage is took as the feedback voltage and brought to the in-phase input port of WCYF, and compare with the voltage of reverse input port, i.e. 1.5V produced by BG, and adjust the output voltage and the sensor current I_{set} of the sensor M5, and make the whole closed loop feedback system in dynamic balance to stabilize the drive current of the power pipe MSG (Shen, 2006).

That is to say, when the sensor current I_{set} increases, the voltage drop on the resistance Rxt will increase, the voltage on the in-phase input of the WCYF will decrease, and the voltage on the reverse input is constant and controlled by the reference voltage source BG of 1.5V, so the output V_{out} of WCYF will decrease and induce the decrease of I_{set}, contrarily, when the sensor current I_{set} decreases, the voltage drop on the resistance Rxt will decrease, so the voltage on the in-phase input of the WCYF will increase, so the output V_{out} of WCYF will increase and induce the increase of I_{set}, which is the principle that the sampling sensor current I_{set} is in the dynamic balance. And the power MOS pipe MSG and the sensor MOS pipe M5 together use the grid and the source and work in the saturation area, so the drive current of the power MOS pipe MSG can be stabilized at 350mA.

(2) The work principle of solar LED system charge and discharge control part.

In Figure 3, C1 and C2 can decrease the ripple current and voltage, and stabilize the input voltage of the system. Because the solar system is different, so both the symbol voltage point to end discharge of the storage battery V_1 and the symbol voltage point to cut off charge V_2 are different. But they can be regulated to 3.3V through potentiometers Rwbgc and Rwbgf and matched with comparable level which operates and amplifies in the interior of the chip. Analogously, the symbol voltage point to turn on LED in different lighting system can be regulated to 1.5V through potentiometer.

The NMOS pipe M1 in Figure 2 is the discharge switch of the storage battery and the load LED switch. When the port voltage of solar panels V_{solar} is smaller than the symbol voltage to turn on LED, i.e. V_{vskg}<1.5V, the voltage will make M1 connect through the automatic disposal of the interior LED switch module KG and exporting high level to automatically turn on LED lamp. When the voltage of the storage battery is smaller than the end voltage of discharge, i.e. V_{vbgf}<3.3V, this voltage exports low level and turns off M1 through the disposal of module KG to implement "over discharge protection".

When the storage battery charges fully, the port voltage of the storage battery is larger than the symbol voltage V_2, i.e. V_{vbgc}>3.3V, this voltage exports high level and connects the switch M0 through the reverse comparing of the interior operational and amplified YF, and at the same time, the Schottky diode SBD1 closes, so the output circuit of the solar panels directly discharges through M0 by bypass and doesn't charge to the storage battery, to avoid over charge for the storage battery and implement the function of "over charge protection".

The Schottky diode SBD1 is the "preventing reverse charge diode", and when the output voltage of the solar battery phalanx is larger than the voltage of the storage voltage, SBD1 can be connected, contrarily SBD1 closes, which can ensure the reverse charge to the solar battery phalanx can not occur at night or overcast and rainy day, and "prevent reverse charge".

Rectifier diode D1 is the "accumulator preventing reverse connection diode", and when the polarity of the storage battery is reverse, D1 connects, which makes the storage battery discharge through the short of D1 and produces large current to melt FUSE 1 quickly and "prevent the reverse connection of the storage battery". The Schottky diode SBD1 is the "solar preventing reverse connection diode", and when the polarity of the solar battery is reverse, SBD2 closes to "prevent reverse connection of the solar battery".

4. Integrated circuit combined simulation and testing

The simulation result of the charge and discharge control part of the solar LED lighting system is seen in Figure 4. From the figure, the charge and discharge part can fulfill the function requirement of the solar controller. Next, we simulate the LED constant current drive part. For the LED load, we select three 1W high-power white light LED made by US CREE Company, and the simulation is implemented under conditions including the temperature of 27℃, $V_{skg} \leq 1.5$, $V_{bgf} \geq 3.3$V and $V_{battery}$=12V. From Figure 5, we can see that when the LED load is three LEDs, the voltage drop range of LED is 9-12V, and the output current of the circuit is 350.75mA, the current precision is ±0.85%. From Figure 6, we can see that when the environmental temperature ascends from -40℃ to 125℃, the current through LED descends from 352.5mA to 346.2mA, decreases 1.79%, which indicates that the chip also has good constant current characteristics when the environmental temperature changes. From Figure 7, we can see that when the output voltage of the storage battery $V_{battery}$ fluctuates in 11V to 14V, the output current of the circuit ascends from 346.3mA to 353.5mA, increases 2.07%, which indicates that the output current of the chip can not be influenced by the storage voltage $V_{battery}$. Figure 8 shows the relationship between the sampling resistance Rxt and the output current I_F, and from Figure 8, we can see that when the sampling resistance Rxt changes in 3.64KΩ~5KΩ, the output current of LED has similar linear relationship with the sampling resistance, and has non-linear relationship in other ranges.

The design of the chip adopts the technology of 0.35μm 2P4M Dual Gate Mixed Mode CMOS offered by Singapore CHARTER, and the total area of the final chip is 1.0mm^2. Figure 9 is the micrograph of the chip, and the testing result of 30 sampling photos shows that the chip can automatically turn on and turn off the LED lamp, implement the charge and discharge regulation of the storage battery and functions of preventing reverse charge, preventing over charge, preventing over discharge, and preventing reverse connection of the storage battery, and the drive current of LED is distributed in 345mA~366mA and most of them is 356mA, which can fully fulfill the use requirement of solar LED lighting system.

5. Conclusions

This article introduces the design and the realization of solar LED lighting system drive control chip based on the technology of 0.35μm CMOS, and the chip can drive LED through constant current of 350mA, and can actualize functions including the regulation of charger and discharge, preventing reverse charge, preventing over charge, preventing over discharge, and preventing reverse connection of the storage battery in the photovoltaic system.

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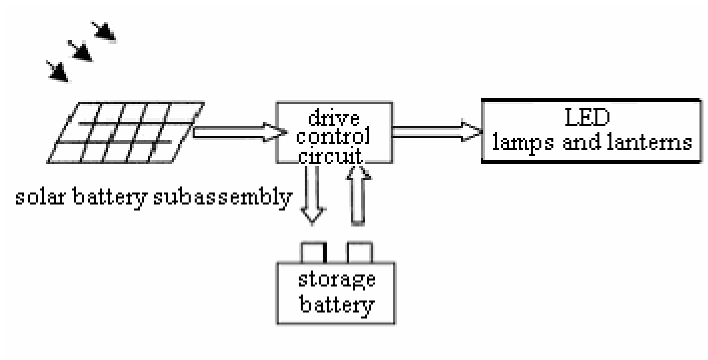

Figure 1. Solar LED Lighting System

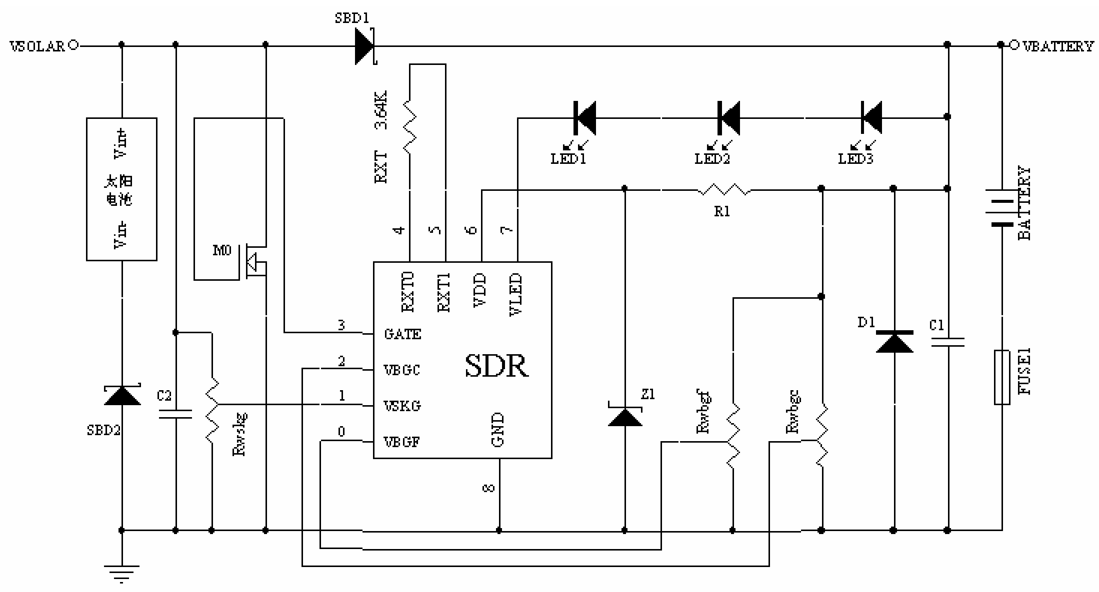

Figure 2. Structure of Chip Principle

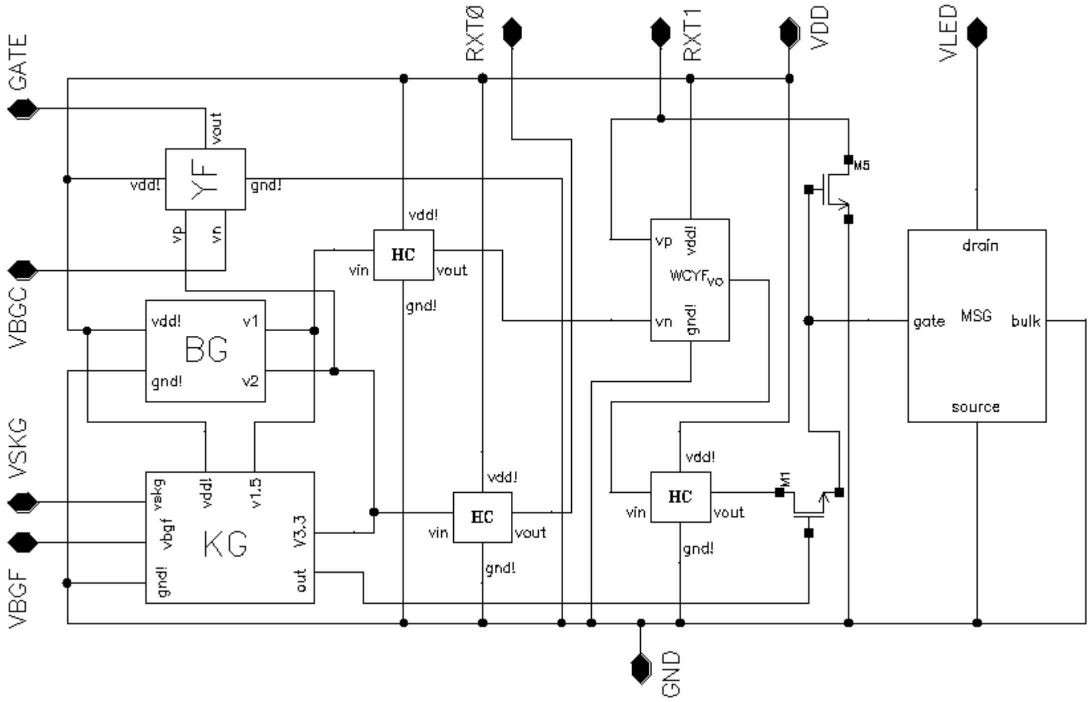

Figure 3. Circuit Diagram of Chip Application

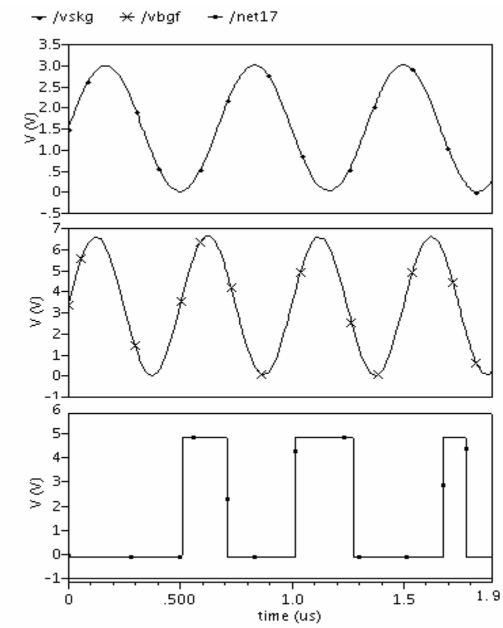

Figure 4. Simulation Waveform of LED Switch

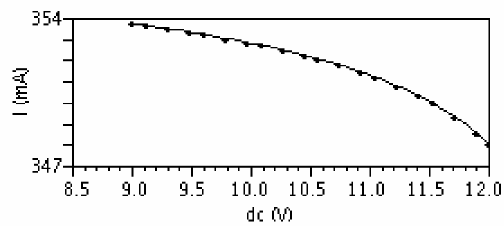

Figure 5. Waveform of LED Output Current

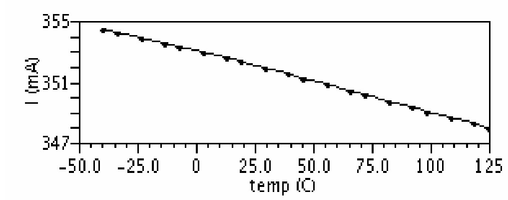

Figure 6. Change Tendency of Output Current When Environmental Temperature Changes

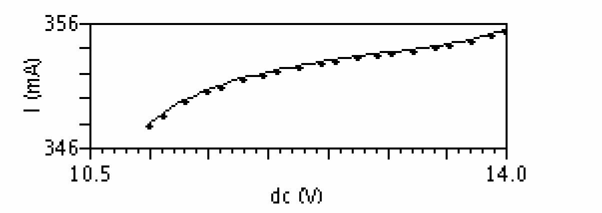

Figure 7. Change Tendency of Output Current When the Voltage of Storage Battery Changes

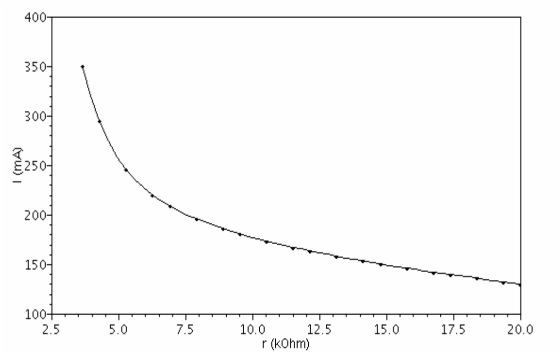

Figure 8. Relationship between the Sampling Resistance Rxt and Output Current

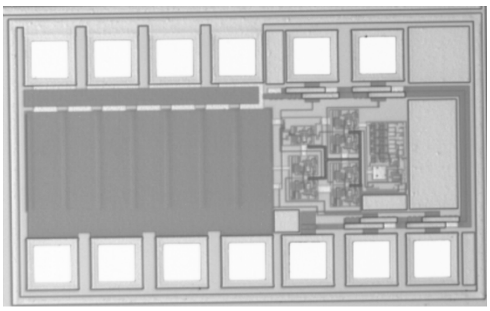

Figure 9. Drive Control Chip