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Design and Simulation of VLC Transmitting System

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Abstract. Low ripple and large bandwidth VLC (Visible Light Communication) transmitting system driven by switching current source is designed to use common LED as transmitter for VLC. Active ripple compensation circuit is designed to eliminate inductance current ripple of switching current source. Wallman differential circuit is adopted to realize LED brightness modulation for transferring information. Simulation results show that the design of VLC transmitting system meets the needs of VLC.

1. Introduction

VLC has a series merits such as no occupation of radio resource, high efficiency, no electromagnetic interference, and saving energy[1]. In order to use common outdoor lighting LED as transmitter for VLC transmitting system, illuminating brightness of LED must be modulated by communication signal and good lighting performance must be maintained. As a result, VLC transmitting system should have characteristics of high bandwidth, high efficiency and constant current output to satisfy the demands of high-speed communication and good lighting effect. Moreover, low output current ripple is required to avoid interference with communication. Therefore, study on low ripple, high bandwidth and high efficient VLC transmitting system has important implications for VLC with common LED.

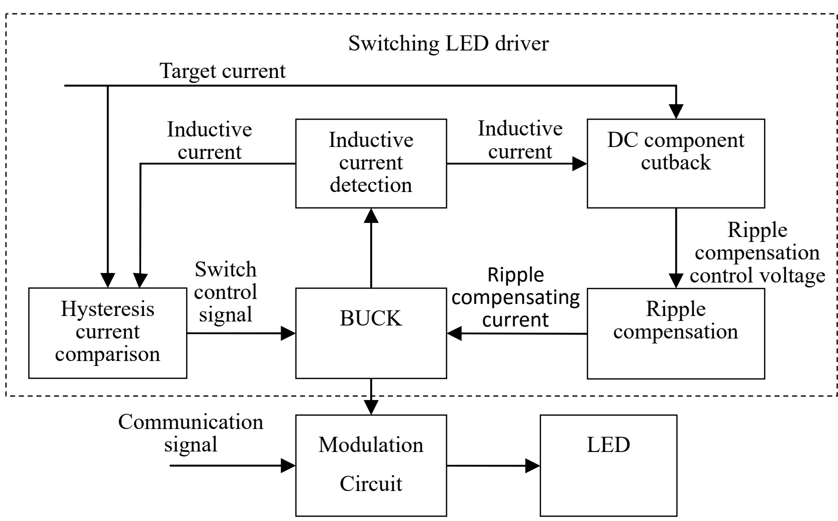

Figure 1. Structure of VLC transmitting system.

2. Design of VLC transmitting system circuit

VLC transmitting system is made up of modulation circuit and switching LED driver, structure of which is showed in Figure 1. With the aid of modulation circuit, LED drive current is modulated by communication signal so that the brightness of LED can be changed with signal. Switching LED driver powers the LED, sets up DC bias of LED drive current, and determines LED illumination, which consists of BUCK module, inductive current detection module, DC component cutback module, ripple compensation module and hysteresis current comparison module.

2.1 Design of modulation circuit

As is shown in figure 2, modulation circuit is a Wallman differential circuit, and i_D is LED drive current. Constant current source IS1 is achieved with the use of switching LED driver, which provides output current i_o. Signal is inputted to modulation circuit through the base of transistor Q3, and added up to the DC bias of LED drive current to generate i_D by means of differential structure; hence LED brightness is modulated by the input signal. Wallman circuit could be considered as a combination of common-emitter circuit and common-base circuit, therefore it is able to combine the virtues of both high input resistance as common-emitter circuit and wide frequency band as common-base circuit[2]. Bode diagram of modulation circuit in usage of transistor 2N3304 is showed in figure 3, which reveals that the modulation circuit has excellent frequency performance as the high-gain is kept within the frequency range of 10MHz. The cut-off frequency is 13.62MHz, and the circuit gain reaches 0dB at the crossover frequency of 100.47MHz.

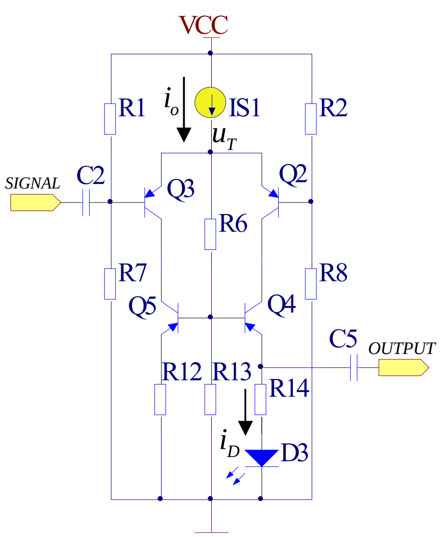

Figure 2. Modulation circuit.

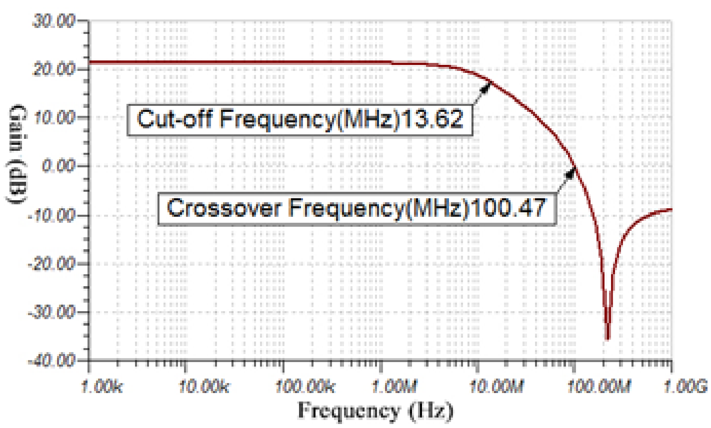

Figure 3. Bode diagram of modulation circuit.

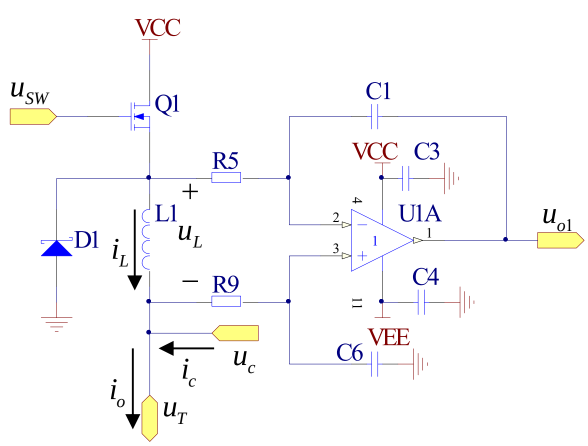

Figure 4. Circuit of BUCK module and inductive current detection module

2.2 Design of switching LED driver circuit

Switching LED driver adopts active ripple compensation circuit to achieve low ripple output current, and adopts hysteresis current control to realize constant current output. Ripple of switching LED driver mainly arises from fluctuation of output current caused by charging and discharging the inductance. Active ripple compensation circuit provides compensating current which is equal and opposite to inductive current ripple, then compensating current and inductive current ripple cancel out each other to realize low ripple output current. Hysteresis comparator turns on or off the switch by comparing inductive current with target current[3]. In comparison to other close-loop control mode, hysteresis current control mode runs without compensation network, which brings advantages of simple circuit structure and fast response. As with average current control mode, hysteresis current control mode aims at average current control so that it is characterized of strong anti-interference and accurate regulation[3].

Switching LED driver consists of BUCK module, inductive current detection module, DC component cutback module, ripple compensation module and hysteresis current comparison module. The circuit of BUCK module and inductive current detection module is shown in figure 4, which is a differential integral circuit with the kernel of operational amplifier U1A. Let $R_2 = R_3 = R$, $L_1 = L$, $C_1 = C_2 = C$, then the relationship between output voltage u_{o1} of inductive current detection module and inductive voltage u_L is

$$u_{o1} = -\frac{1}{RC}\int u_L dt \tag{1}$$

The relationship between inductive current i_L and u_L is

$$u_L = L\frac{di_L}{dt} \tag{2}$$

Put (2) into (1) then u_{o1} is written as

$$u_{o1} = -\frac{L}{RC} i_L \tag{3}$$

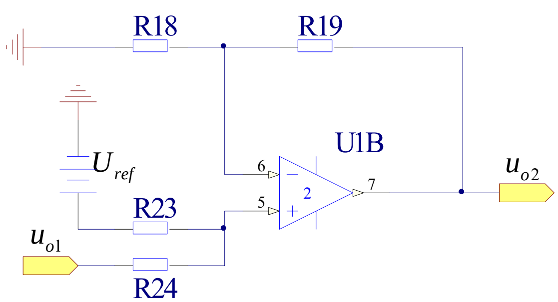

Figure 5. Circuit of DC component cutback module.

DC component cutback module is used to obtain inductive current ripple by cutting the DC component away from inductive current. In a practical application, the target of average inductive current (reference voltage U_{ref}) is subtracted from practical inductive current to cancel out DC component, and this results in negative-feedback which speeds up the circuit response. The circuit of DC component cutback module is shown in figure 5, which is an adder with the kernel of operational amplifier U1B. Let $R_{18} = R_{19}$, then output voltage u_{o2} of DC component cutback module is

$$u_{o2} = u_{o1} + U_{ref} = -\frac{L}{RC} i_L + U_{ref} \tag{4}$$

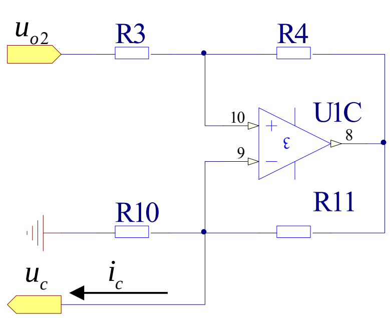

Figure 6. Circuit of ripple compensation module.

Ripple compensation module produces compensating current in accordance with inductive current ripple. As is shown in figure 6, the circuit of ripple compensation module is a Howland voltage-controlled current source with the kernel of operational amplifier U1C[4]. When $R_3/R_4 = R_{10}/R_{11}$, compensating current i_c is[4]

$$i_c = \frac{u_{o2}}{R_3} \tag{5}$$

The compensating current i_c and inductive current i_L flow into the same branch to generate output current i_o, as is shown in figure 4. Then

$$i_o = i_c + i_L \tag{6}$$

The inductive current i_L comprises DC component I_L and ripple component i_r, then i_L is written as

$$i_L = I_L + i_r \tag{7}$$

Put (4), (5), (7) into (6) then i_o can be expressed as

$$i_o = \frac{U_{ref}}{R_3} - \frac{L}{R_3RC} i_r - \frac{L}{R_3RC} I_L + i_r + I_L \tag{8}$$

As is shown in formula (8), inductive current ripple can be completely eliminated when $L = R_3RC$.

Hysteresis current comparison module is used to turn the switch of BUCK module on or off in accordance with the comparison between inductive current and target limits. As is shown in figure 7, hysteresis current comparison module consists of Schmitt trigger and switch drive circuit, and controls the switch through node u_{SW}.

3. Simulation and analysis

Simulation of VLC transmitting system circuit is shown in figure 8, and simulation results are shown in figure 9. Figure 9(a) shows that compensating current and inductive current ripple are able to cancel out each other since $i_c(t) = -i_r(t)$. Figure 9(b) shows that since i_o has very few ripple, design of switching LED driver meets the requirement of

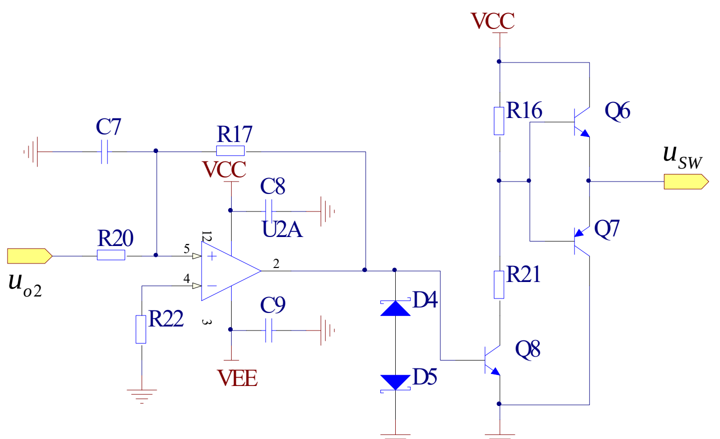

Figure 7. Circuit of hysteresis current comparison module.

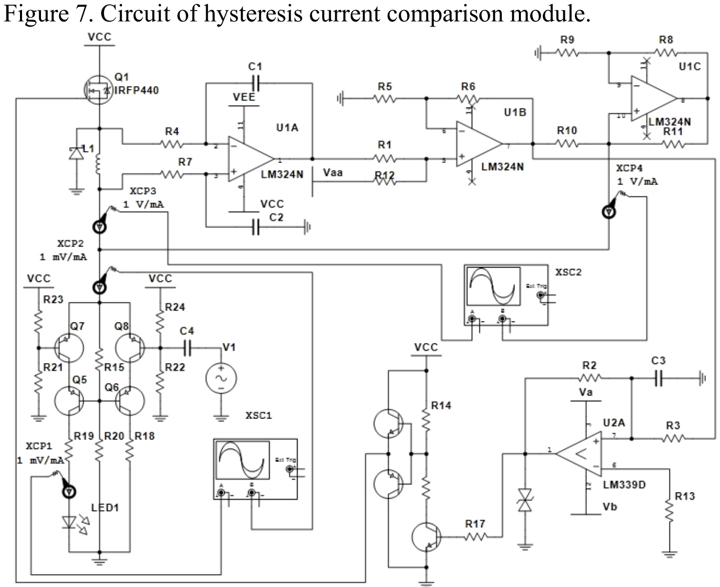

Figure 8. Simulation of VLC transmitting system circuit with Multisim.

VLC. With the aid of modulation circuit, 100MHz sinusoidal signal generated by source V1 has been added up to DC bias current produced by switching LED driver to generate LED drive current i_D. As is shown in figure 9, the wave form of i_D is undistorted, and the brightness of LED is able to be modulated to high speed signal with the change of i_D. Therefore, VLC is able to be realized.

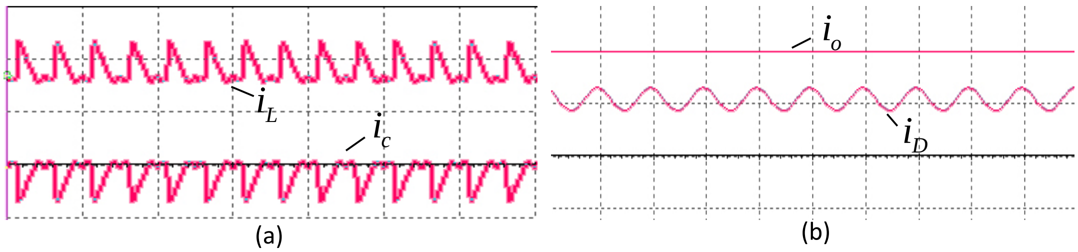

Figure 9. Simulation results with Multisim.

Conclusion

VLC transmitting system adopts active compensation circuit to eliminate inductive current ripple and realize low ripple output of switching LED driver; brightness of LED can be modulated by high speed signal with the use of Wallman differential circuit. The simulation results show that the design of VLC transmitting system meets the engineering objectives of low ripple, high bandwidth and high efficiency. The realization of VLC transmitting system is conductive to promote the use of VLC.

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