Lech GRODZKI

Bialystok University of Technology

LED Driving Circuits Without Feedback

Abstract. *In many contemporary LED lamp applications specialized controllers can stabilize the luminous flux of LED lamp at ordered level or change its value according to the selected algorithm. The properties of LED devices allow to control the luminous flux in open loop system. That simplified control technique can be matched to the applied LED driving circuit. The article contains some examples of realizations, using digital technique, especially microcontrollers, FPGA devices and specialized integrated drivers. The features of each realization are pointed, too.*

Streszczenie. *Wiele współczesnych zastosowań oświetleniowych lamp LED wykorzystuje specjalizowane sterowniki do uzyskiwania pożądanej jasności ich świecenia, stałej lub zmiennej w czasie. Właściwości LED umożliwiają regulacją ich strumienia świetlnego w układzie otwartym. Upraszcza to konstrukcję różnych obwodów sterujących. Artykuł zawiera przegląd szeregu takich rozwiązań, ze wskazaniem ich cech użytkowych. (**Układy sterowania LED bez sprzężenia zwrotnego**)*

Keywords: PWM LED driving, constant-current LED driving, LED dimming, control efficiency
Słowa kluczowe: sterowanie PWM, sterowanie stałoprądowe, regulacja jasności LED, sprawność sterowania

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LED luminance control

The possibility of controlling the luminous flux is getting very important feature of modern lighting device based on LED. It allows to use LED lamp in energy-saving mode and create different versions of illumination. The most precise technique for control of any output value is system with feedback. Such system used with lighting device allows to: stabilize the output value of the luminous flux Φ at ordered level Φ^*, realize the ordered changes of its value and compensate the changes of LED working point due to ambient conditions or time [1, 2].

LED as an object of the control

Designing LED luminous flux control unit we should take into account several physical quantities. The LED working point is determined by its forward voltage U_F and forward current I_F, temperature of the structure T_D, and also the ambient temperature T_{AMB}. The typical relations between mentioned quantities and LED luminous flux Φ can be found in LED datasheets as working characteristics. For example, the precise control unit for stabilizing the coloured LED devices should measure not only voltage or current but also temperature of the LED case [2, 3]. Unfortunately such precise regulators are too expensive for general use. This is why designers often replace the temperature feedback by cooled radiators or do not use any feedback at all. In this second case the knowledge about LED working characteristics are very important. Although they are nonlinear, they can be easy described either by mathematical formulas or tables of values.

Examples of control circuits

Voltage converters and controlled suppliers

The first type of widely used control units are controlled suppliers and voltage converters. They simply adjust their output voltage supplying the LED device [4, 5]. The modern construction of such devices allows to control the output voltage by analogue or digital signals, so they can be used as actuators in luminous flux control systems. These solutions have following features:

- complex internal structure based on specialized chips and discrete elements;
- the necessity of usage supervising microcontroller, which has to calculate nonlinear dependences between LED supplying voltage and luminous flux;
- lower integration scale in comparison with further presented solutions.

PWM modulation

The next very popular technique is based on PWM signals. At constant supplying the energy transferred to the LED is proportional to the duty coefficient D:

(1) $$P = D \cdot P_{MAX}$$

The usage of PWM signals causes the sequence of light pulses. If the frequency of PWM signal is high enough, the human eye observes continuous light. The relation between duty coefficient D and observed by eyesight luminous flux is practically linear – the appropriate measures were made for monochromatic, white and RGB LEDs. The exemplary results are presented in table 1. They proved the usability of PWM technique for luminous flux control in open loop system.

Table. 1. Relation between duty coefficient D and relative value of luminous flux Φ_r

D [-]	0,2	0,4	0,6	0,8	1
Φ_r [-]	0,22	0,43	0,62	0,82	1

The realization of PWM LED control is usually based on the circuit determining the moments of switching the output transistor – figure 1. The frequency of pulse generator G divided by the counter capacity determines the frequency of output PWM signal. The number of bits of the counter, comparator and register determines the accuracy of the control. In practice, the PWM technique can be implemented for several ways.

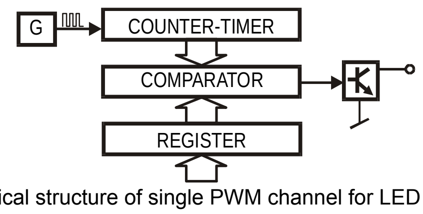

Fig. 1. Logical structure of single PWM channel for LED driving

Very popular implementation of PWM LED control is the usage of the specialized counter-timer units built-in microcontrollers [7]. The number of PWM channels created in this way depends on the type of microcontroller and varies from one to almost twenty per single chip. Microcontroller PWM units have at least 8-bit resolution, what gives the accuracy about 0,4%, which is quite sufficient for the most LED lighting applications. Of course the complete driving circuit needs external transistor switches (Fig. 2) and appropriate software.

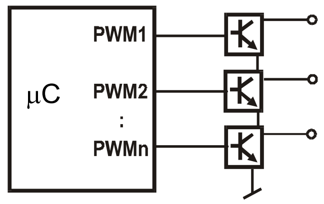

Fig. 2. Multichannel PWM controller with microcontroller

The usage of microcontrollers for PWM LED driving has the following features:

- simple structure with minimal number of components;
- possibility of implementation in microcontroller software not only PWM algorithms, but also additional utilities;
- the utilization during designing and developing processes the basic, sometimes free designing tools;
- limited, depended on type of the chosen microcontroller, number of working simultaneously PWM channels;
- sometimes increased amount of necessary program calculations, what makes the implementation of additional algorithms difficult.

The PWM LED driving channel can be also implemented inside the FPGA structure [8]. In such solution the number of simultaneously working channels is limited by internal resources and the number of accessible I/O terminals of the programmable structure. The practical realization of PWM channels in FPGA device also needs a microcontroller as a supervising unit (Fig. 3).

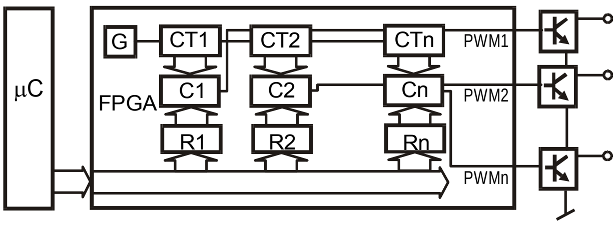

Fig. 3. Multichannel PWM controller implemented in FPGA device

The usage of FPGA structures for multichannel PWM LED driving has the following features:

- potentially big number simultaneously working PWM channels;
- possibility of utilization any microcontroller as the supervising unit;
- decreasing the number of tasks managing by the microcontroller software;
- more complex circuit, with a higher cost of a single driving channel;
- necessity of usage specialized developing software for FPGA devices.

The last possible way of realization the PWM LED driving is the usage of specialized integrated circuits, offered by several manufacturers [9, 10, 11]. Those chips have built-in switching transistor. LED brightness control is usually realized by sending to the chip the value of duty coefficient via serial interface. So supervising microcontroller is also necessary. The utilization specialized chips for PWM LED driving has the following features:

- simplification of designing process – control unit is completed using ready blocks;
- possibility of utilization any microcontroller as the supervising unit;
- availability of additional functions realized by specialized chips, like overtemperature protections, etc.

The PWM technique used for LED luminous flux control has always one important feature: it causes the emission of strong light pulses, what can be sometimes considered as disadvantage.

Double PWM modulation

It is a modification of basic PWM technique. In this method the single low frequency (100..300Hz) signal is replaced by the superposition of two PWM waveforms [12]: u_{LF} with low frequency (like in standard PWM modulation) and u_{HF} with high frequency (for example 50kHz) – figure 4a. Proposed solution allows to simultaneous control of the LED pulse current and its average value.

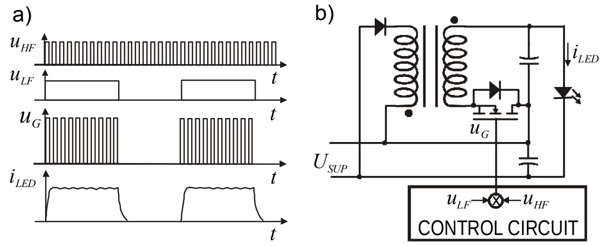

Fig. 4. Double PWM LED dimming: a – waveforms of controlling voltages and LED current; b – exemplary circuit

Proposed DPWM technique has the following features:

- simple switching circuit but containing inductors and capacitors;
- high efficiency driving circuit;
- LED current regulation is realized directly by the power converting circuit;
- LED dimming is achieved by low frequency PWM modulation;
- logic control circuit should be based on dedicated IC or microcontroller;
- emission of strong light pulses.

PAM modulation

Pulse amplitude modulation is well-known technique of changing the average value of controlled quantity. In application for LED supplying it is usually based on constant frequency and duty cycle of the rectangle waveform. Only the amplitude of pulses can be changed. Practical realization of LED driving circuit without feedback needs the microcontroller or specialized IC. It is caused by the nonlinear relation between luminous flux and LED forward current. This US and GB patented technique is used in LED dimming equipment offered by several manufactures [13].

The PAM technique, like PWM, causes the emission of strong light pulses. But in comparing with PWM it has one important advantage. During dimming of RGB LED no other temporary colours than ordered and black are observed (Fig. 5a). While in PWM technique fast camera can record some others colours (Fig. 5b).

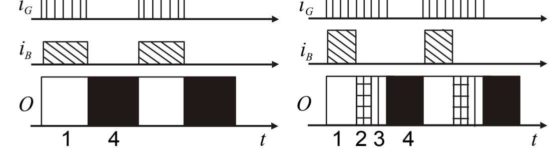

Fig. 5. The influence on the observed temporary colour O in PWM (a) and PAM (b) technique during dimming of RGB LED: i_R, i_G, i_B – forward currents of RGB components; temporary colours: 1 – white, 2 – yellow, 3 – green, 4 - black

Constant-current driving

The method alternative to PWM technique is the constant-current LED driving [14, 15, 16]. This method uses the knowledge about the relation between LED forward current I_F and its luminous flux Φ. Using LED datasheets or measuring appropriate characteristics is possible to approximate that relation either by algebraic function or table of values. Formula (2) is the result of such approximation for exemplary POWER LED.

$$\widehat{\Phi}_R = \sqrt{2}\ln(1 + I_R) \qquad (2)$$

where I_R means relative LED forward current, Φ_R – relative luminous flux.
To obtain ordered luminous flux Φ_R, it is necessary to adjust the LED forward current I_R to the value calculated using inverse function of (2):

$$\widehat{I}_R = e^{\frac{\Phi_R}{\sqrt{2}}} - 1 \qquad (3)$$

Of course, above calculations are possible if we use supervising microcontroller. Instead algebraic function (3), microcontroller software can use the table of values of this function. In addition we do not need to build controlled current sources – several IC-manufacturers offer specialized chips [9, 10, 11, 17], for driving from one to over twenty output channels, each with separate controlled current source. The chips allow to control the output currents simultaneously or independently. The current control is realized by supervising microcontroller via digital serial interface (SPI or I2C), as it is shown on figure 6.

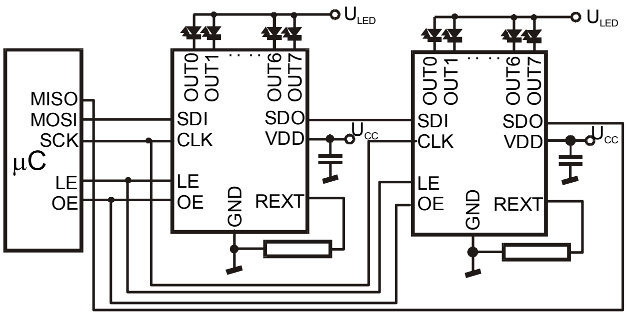

Fig. 6. An example of constant-current driving circuit for 16 LEDs

Serial interface is used to transfer 7-bit words controlling current efficiency for every output channel. The exemplary accuracy of control is equal 0,8%. These specialized ICs usually have another useful facilities, for example short-circuit or break detection, etc. The constant-current LED driving based on specialized chip has the following features:

- possible big number of simultaneously working channels, obtained by cascading the chips;
- only few additional, external elements to build complete control unit;
- possibility of utilization any microcontroller as the supervising unit;
- decreasing the number of tasks managing by the microcontroller software;
- the utilization during designing and developing processes the basic, sometimes free designing tools;
- continuous luminous flux without any light pulses.

Conclusions

The common feature of the solutions presented in the article is the utilization of microcontrollers working either as main controlling unit or as only supervising unit. The presence of microcontrollers in LED driving devices allows to realize additional functions, like building bigger lighting systems, coordination the work of several controllers, realizing more complex control algorithms for groups of LEDs. The article points the availability of specialized integrated circuits useful for different LED driving methods, which allow to build control units working with sufficient for many applications accuracy. Selection one of the possible solutions depends on different conditions:

- availability and cost of components;
- design simplicity and availability of designing tools;
- the number of LED devices to be controlled;
- energy-saving aspects [18];
- the acceptance or not pulse lighting, even invisible for eyesight.

Thorough analysis of above conditions allows to chose the best design solution.

Presented results are the part of research work No S/WE/1/11.

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***Author:** Lech Grodzki, dr eng., Białystok University of Technology, Faculty of Electrical Engineering, Wiejska 45D, 15-351 Bialystok, E-mail: lgrodzki@we.pb.edu.pl*