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Article

Operation of Electronic Devices for Controlling Led Light Sources When the Environment Temperature Changes

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Abstract: Ambient temperature significantly affects the electrical and light parameters of LEDs, such as forward and reverse current, voltage drop LEDs and luminous flux. With an increase in temperature, the decrease in the intensity of LED radiation is explained by physical processes, including the phenomena of non-radiative recombination due to impurity levels, recombination on the surface, losses carriers in the barrier layers of heterostructures, etc. The increase in temperature is also significantly reduces the useful life of LEDs and the LED device in general. Drivers, which allows to stabilize the operating current with a change in the supply voltage of the device and, as the result is light flux. But in LEDs of various types, current stabilization does not lead to the stabilization of the light flux when the temperature regime of their operation changes. When changing ambient temperature in the range of +40 . . . +60 °C, the luminous flux of LEDs is significant decreases even in the case when their current is kept constant, as we can see from documentation for most of LED types. An article analyzes the effect of temperature on electrical and light parameters LEDs with different types of drivers as part of LED lighting devices, such as LED lamps and LED spotlights, in order to offer possible constructive solutions for partial reduction or elimination of the decline problem luminous flux of LED devices under conditions of their operation at high temperatures.

Keywords: LED lamp; LED spotlight; experimental characteristics; temperature dependence of LED parameters; driver schemes

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1. Introduction

The trend for the last years is the widespread introduction of LED lighting, which replaces thermal and gas-discharge light sources [1,2]. All LED lamps can be divided into LED lamps for indoor use, which replace incandescent lamps, and lamps for outdoor use lighting. The last one should work in a wide range of temperatures [3,4]. Most structures of LED lighting devices are built on the basis of electronic control circuits (drivers), which can be conventionally divided into the following types [5–8]:

(1) Drivers that do not compensate for changes in electrical and lighting parameters when the network voltage changes, this also includes simple linear ballast circuits without current stabilization (linear drivers);
(2) Linear drivers with LED current stabilization, where resistors are usually used as current feedback (linear driver circuits). Such drivers are most often built according to the high-voltage compensating scheme current stabilizers, where the compensating one's were gradually connected with the LEDs element (field effect transistor);
(3) impulse drivers built, for example, with generators with wide pulse modulation (PWM), where the load current is determined by the density output pulses at a

constant value of their frequency (IS drivers). They are mainly used in power chains of more powerful lighting devices, for example, in street lights or floodlights. They have a relatively high efficiency (up to 95%).

As the analysis of the circuits shows, in most of the drivers listed above, there is no compensation for changing the light parameters of LEDs or LED matrices (light flux) when the temperature regime of their operation changes, although this effect is very significant [9,10]. The temperature dependence of the intensity of LED radiation is most significant in cases where LEDs are operated in outdoor conditions environment. For example, in summer, the temperature of the environment is quite high, and the level of outdoor lighting is also high. In these conditions, the light source should be brighter, but the luminous flux of LEDs decreases with increasing temperature. Therefore, to compensate for this decrease, it is necessary not to stabilize the LED current, but conversely, to increase it.

Goals of this article:

- definitioning the effect of ambient temperature on the parameters of LED lighting devices built on different types of drivers;
- estimate of the ability of various driver schemes used to power LEDs to stabilize the operating current not only when the supply voltage changes, but also when the ambient temperature changes;
- definitioning the adequacy of the influence of temperature on the parameters of LED devices only according to those characteristics that are given in the technical documentation on one or another type of LEDs (datasheet), based on the obtained experimental temperature characteristics;
- development of constructive proposals for the structure of drivers of LED light sources, which could partially or completely compensate for temperature efficiency radiation intensity of LEDs when the temperature regime of their operation changes.

To achieve these goals, we will provide a study of the characteristics of LEDs that can be used to assess the effect of temperature environment on the light and electrical parameters of the LED device, namely: the dependence of the forward voltage of the LED Ud on the temperature Tc at a constant (nominal) value of the current and the dependence of the relative value of the luminous flux of the LED F/F0 from the temperature T_c [11].

2. Investigation of Temperature Dependence of Current and Luminous Flux

2.1. Investigation of Temperature Dependence of Current and Luminous Flux of LED Lamps Based on Linear Drivers

It is well known that with the increase in the environment temperature T_c at constant value of LED current, the luminous flux of the LED decreases significantly [12,13]. Therefore, in LED devices, the effect of temperature on their light parameters is significant. The temperature changes in electrical and lighting parameters are especially noticeable while using LEDs outdoors. Especially in summer, when high temperature conditions can cause noticeable reduction in the luminous flux of LEDs. Most circuits of linear and current stabilization drivers in LED lighting devices have the capability to stabilize the current in both cases when the supply voltage and when the environment temperature is changing. But, as a rule, in such cases not all of them able to guarantee stability of light parameters (illuminance, luminous flux) of LED devices.

In order to confirm this assumption, we will provide the investigation concerning the changes of current and illumination, luminous flux of LED devices with different typesof drivers depending on the temperature. Let's have a look at the temperature dependence of current and luminous flux of LED lamps on the basis of linear drivers (Figure 1).

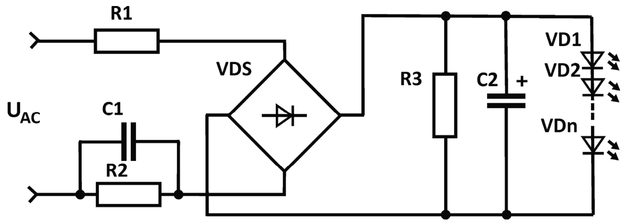


Figure 1. Schematic diagram of LED lamp with linear driver.

The investigated devices were placed in the thermostat, the temperature varied from +15 °C to +60 °C in increments of 5 °C. The investigations are carried out at AC mains voltage of 198 V, 220 V or 242 V.

At the same time, the values of the consumed alternating current I_{inp}, ambient temperature T_c, LED voltage U_d, LED current I_d and illuminance E were measured.

Block diagram of measurements is shown in Figure 2.

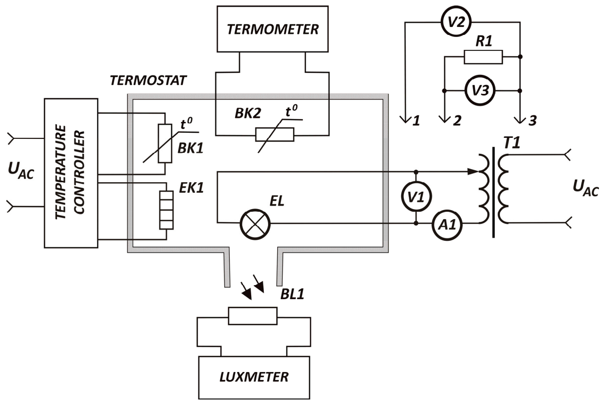


Figure 2. Block diagram of measurements.

The main experimental installation is shown in Figure 2. The basis of the setup thermostable chamber "TERMOSTAT", in which EL LED lamp is installed. Chamber cooling is based on natural conventions. Electronic thermometer VK2 (type TRM-10) was used for independent temperature control. The current EL LED lamp and its voltage were controlled by an ammeter A1 and voltmeter V1, respectively. Voltmeters V2 and V3, together with 1 Ohm resistor R1, were determined the voltage and current flowing through the diodes of the LED lamp. For more accurate measurement of the illuminance, the walls of the thermally stabilized chamber was painted black. The illuminance was measured with the luxmeter, its sensitive element BL1 was isolated from external light. Led lamps LedEX E27B with power 3 W and 6 W were investigated. Their basic electrical scheme is shown in Figure 1. The general view of the lamps without the plastic diffuser is shown in Figure 3.

(**a**) (**b**)

Figure 3. LedEX E27B LED lamps with 3 W (**a**) and 6 W power (**b**).

LedEX E27B lamp (3 W) contains six SMD 2835 LEDs (nominal voltage 18 V, current 30 mA, power 0.5 W, color temperature 4000 K) [14,15] (Figure 3a). LEDs were connected gradually. Experimental dependencies of the relative current values I_{inp}/I_{inp25} of this LED lamp on the environment temperature T_c at supply voltages of 198 V, 220 V and 242 V, where I_{inp25} is the lamp current value at +25 °C temperature and 220 V supply voltage is shown in Figure 4. The value of input current in the scheme of Figure 1 can be considered as equal to the current through LEDs.

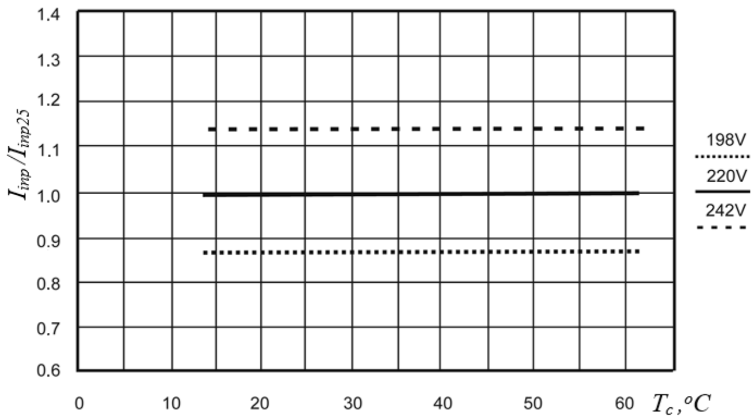


Figure 4. Dependencies of relative current values I_{inp}/I_{inp25} on temperature T_c at 198 V, 220 V and 242 V supply voltages for p = 3 W lamp.

Illuminance E from LED light sources was measured by luxmeter. But, the application of illuminance relative values E/E_{25}, where E_{25} is illuminance at +25 °C temperature, makes it possible to confirm that the dependence will be the same for relative values of luminous flux F/F_{25} of the lamp or spotlight ($E = F/A$, where F is luminous flux, A is the area of the illuminated surface).

The experimental dependencies of the relative values of the LED lamp is luminous flux F/F_{25} on the environment temperature T_c at 198 V, 220 V and 242 V supply voltages, where F_{25} is the value of the lamp luminous flux at +25 °C and 220 V supply voltage were shown in Figure 5.

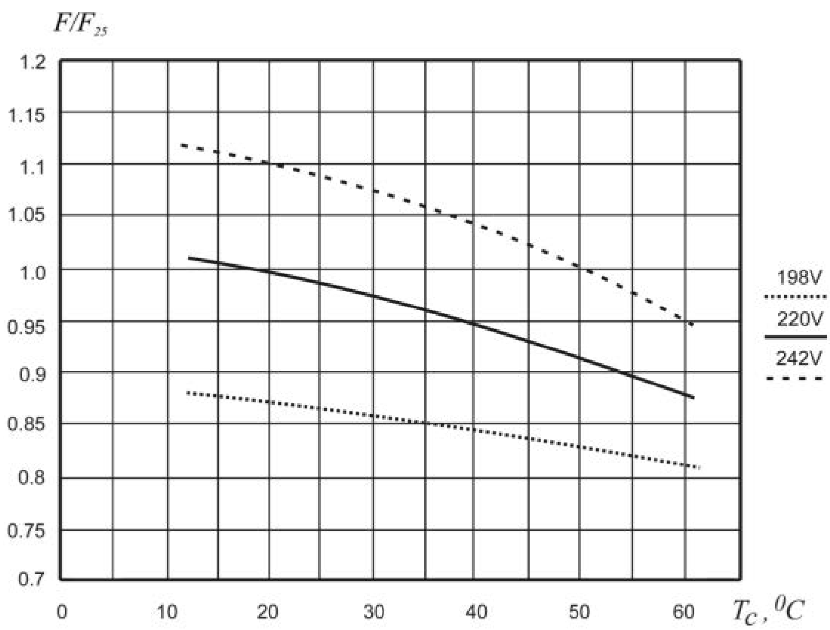


Figure 5. Dependencies of the relative values of the luminous flux F/F_{25} on T_c temperature at 198 V, 220 V and 242 V supply voltages for p = 3 W lamp.

The dependence of voltage relative values U_d/U_{d25} on the LEDs of lamp on the environment temperature T_c at supply voltages 198 V, 220 V and 242 V, where U_{d25} is the voltage on LEDs at +25 °C and supply voltage of 220 V was shown in Figure 6. The value of the current through the LEDs was considered to be unchanged (Figure 4).

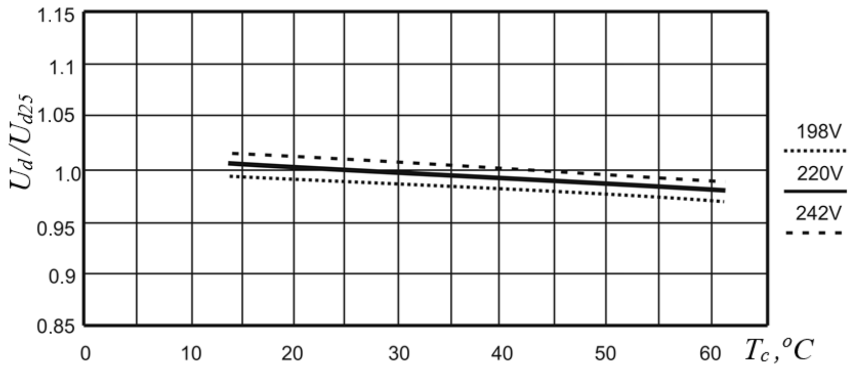


Figure 6. Dependencies of the relative voltage values U_d/U_{d25} of LEDs lamp on temperature T_c at 198 V, 220 V and 242 V supply voltages for p = 3 W lamp.

As can be seen from the graphs shown in Figure 4, the linear driver circuit does not provide current stabilization when the supply voltage changes. But, at the same time, it is possible to observe the absence of current dependence on the temperature at different values of supply voltage.

The change of luminous flux with temperature is significant (Figure 5) and within +15 . . . +60 °C; temperature range at 198 V voltage is up to 8%, up to 13% at 220 V voltage, and up to 17% at 242 V voltage. That is, with the increase of current through LEDs relatively to its nominal value, the luminous flux drops increase.

LedEX E27B lamp with power 6 W contains eleven SMD 2835 LEDs (nominal voltage 18 V, nominal current 30 mA, power 0.5 W, color temperature 4000 K) (in Figure 3b—the general view of the lamp without light diffuser). LEDs were connected gradually.

The dependence of the current relative values I_{inp}/I_{inp25} for 6 W LED lamp on the environment temperature T_c at 198 V, 220 V and 242 V supply voltages was shown in Figure 7, and the dependence of the relative values of F/F_{25} luminous flux of the 6 W LED lamp on the environment temperature T_c at 198 V, 220 V and 242 V supply voltages was shown in Figure 8.

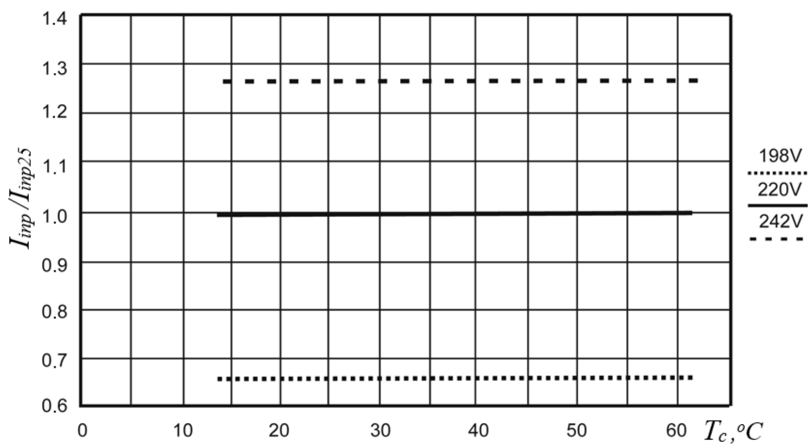


Figure 7. Dependencies of the relative current values I_{inp}/I_{inp25} on T_c temperature at 198 V, 220 V and 242 V supply voltages for p = 6 W lamp.

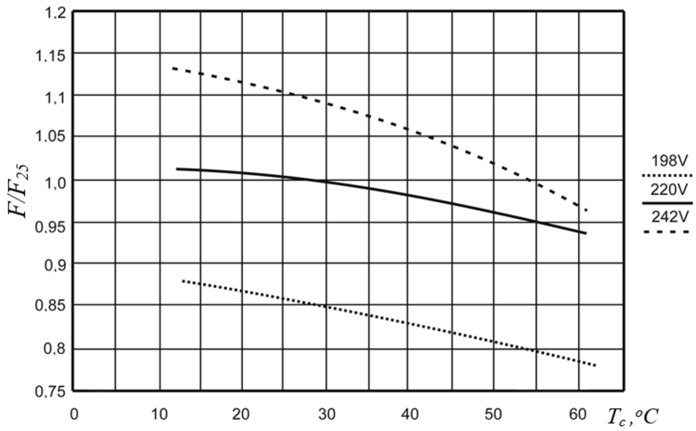


Figure 8. Dependencies of the relative luminous flux values F/F_{25} on T_c temperature at 198 V, 220 V and 242 V supply voltages for p = 6 W lamp.

Dependencies of the relative voltage values U_d/U_{d25} of LEDs lamp with power 6 W on T_c environment temperature at supply voltages 198 V, 220 V and 242 V was shown in Figure 9.

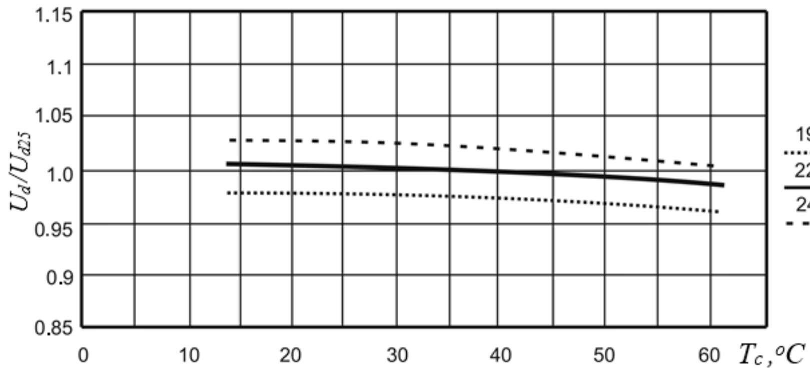


Figure 9. Dependencies of the relative voltage values U_d/U_{d25} of LEDs lamp with power 6 W on T_c environment temperature at 198 V, 220 V and 242 V supply voltages for p = 6 W lamp.

If we compare dependencies that shown in Figures 4 and 7, we can see that if U_{AC} voltage changes by 10%, the input current of 6 W lamp changes twice as much as 3 W lamp and is more than 25%. This can be explained in the following way.

The dependence of LEDs relative current change for LED lamp on the relative network voltage change can be written as follows [11,16]

$$\varepsilon I_d = \varepsilon U_a/(1 - U_d/U_a), \tag{1}$$

where εI_d is relative current change through LEDs, εU_a is a relative change in the amplitude of network voltage, U_d is voltage on LEDs.

$$\varepsilon I_d = \varepsilon U_a/(1 - U_d/U_a). \tag{2}$$

If U_d value approaches to the value of the amplitude of the network voltage U_a, the relative change in current through LEDs is sufficiently greater than the relative change of the network voltage.

As in the case with 3 W lamp (Figure 4), the current of 6 W lamp (Figure 7) at different values of supply voltage practically does not change with temperature. The change of luminous flux with temperature is significant (Figure 8) and within +15–+60 °C temperature range is up to 10% at 198 V voltage of, up to 8% at 220 V voltage, and up to 17% at 242 V voltage. Voltage on LEDs for both 3 W lamp (Figure 6) and 6 W lamp (Figure 9) practically did not change with temperature changes and slightly depends on U_{AC} voltage.

2.2. The Investigation of Temperature Dependencies of the Current and Luminous Flux of the LED Lamp Built on IC Driver with Voltage Pulse-Width Modulation of the Voltage on LEDs

Premier-10 E27 LED lamp with power 10 W produced by HOROZ ELECTRIC trademark was investigated (Figure 10, general view without light diffuser).

Figure 10. Premier-10, 10 W LED lamp.

The lamp contains nine SMD 2835 LEDs (nominal voltage 12 V, nominal current 75 mA, power 1 W, color temperature 4000 K) [17]. LEDs were connected gradually.

Principle electric scheme of Premier-10 lamp is shown in Figure 11.

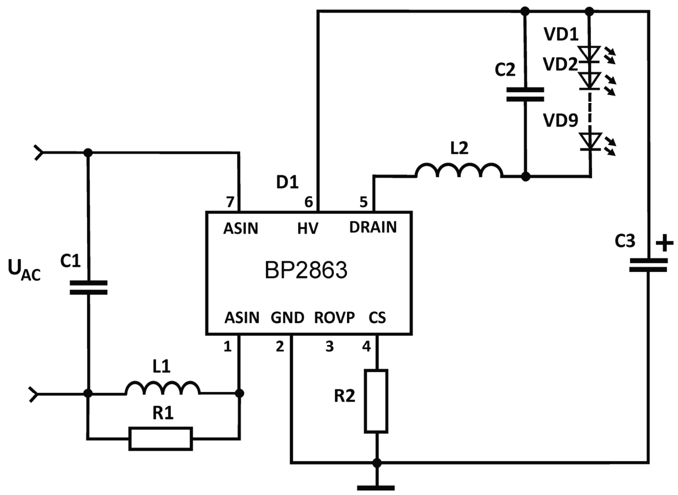


Figure 11. Principle electric scheme of Premier-10 lamp with 10 W power.

The lamp driver is made on BP2863 chip, the structure of which is shown in Figure 12 [18].

Chip *D1* is high-frequency converter with pulse width regulation of the output voltage (DRAIN output), switched on LEDs were connected to it gradually through *L2C2* filter elements (Figure 11). The current through on the LEDs is constant. The microcircuit, in fact, is *current stabilizer*, where the regulating element was the field-effect transistor (Figure 12), and current sensor was the resistor *R2* (Figure 11). The current through LEDs was regulated by pulse density at DRAIN output.

The oscillogram of the voltage at DRAIN output circuit (Figure 11) at U_{AC} = 220 V supply voltage was shown in Figure 13. Dependencies of relative current values I_{in}/I_{in25} of this LED lamp on environment temperature T_c at various supply voltages (198 V, 220 V and 242 V) was shown in Figure 14.

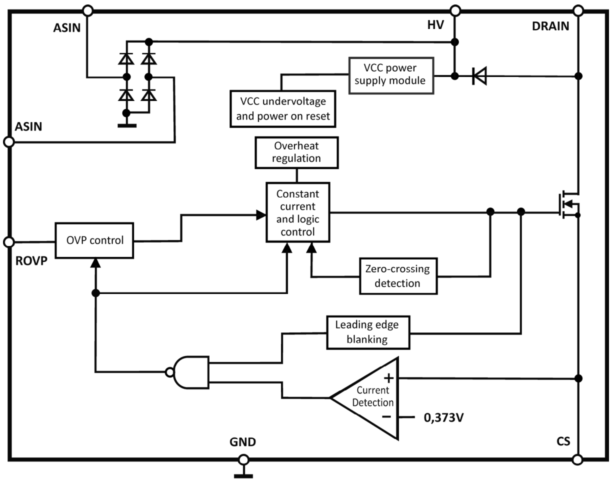


Figure 12. Functional diagram of BP2863.

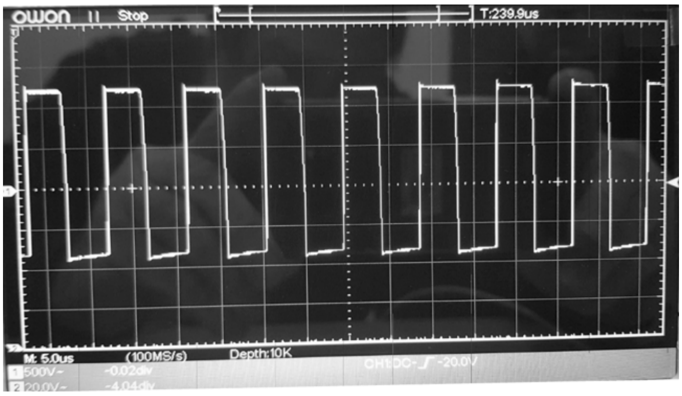


Figure 13. Voltage oscillogram at DRAIN output of BP2863.

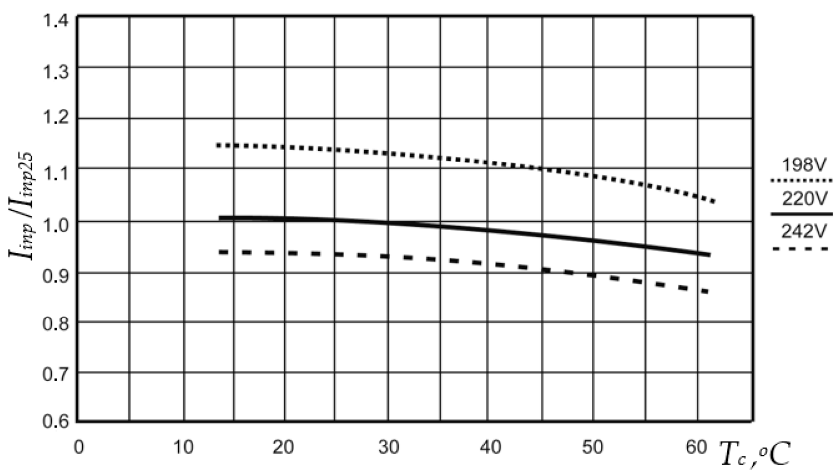


Figure 14. Dependencies of current relative values I_{inp}/I_{inp25} on T_c environment temperature at198 V, 220 V and 242 V supply voltage for Premier-10 lamp.

It is evident from the obtained dependencies, that if U_{AC} voltage decreases, the input current of the lamp increases, the amplitude of the pulses at DRAIN output of the circuit decreases, and when the voltage increases, the input current decreases and the amplitude of the pulses increases. In the first case, the duration of the pulses at DRAIN output of the microcircuit increases, in the second—it decreases, ensuring current stabilization through the LEDs.

The dependencies of current relative values I_d/I_{d25} of LEDs on the environment temperature T_c, where I_d is current value of the current, I_{d25} is the current value at +25 °C and U_{AC} = 198 V, 220 V and 242 V were shown in Figure 15.

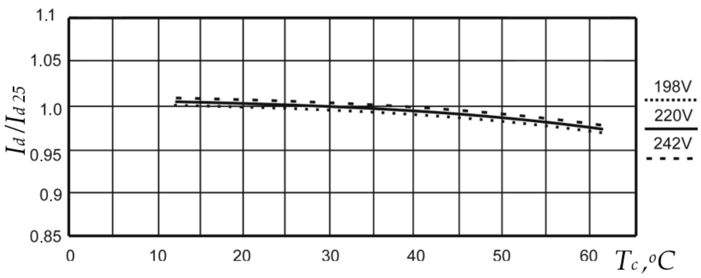


Figure 15. Dependencies of current relative values I_d/I_{d25} on the environment temperature T_c at 198 V, 220 V and 242 V supply voltage for Premier-10 lamp.

The value of the current through LEDs practically did not changed with the change of supply voltage U_{AC}. Dependencies of the voltage relative values U_d /U_{d25} of the lamp LEDs on temperature T_c were shown in Figure 16. Both current and voltage on LEDs practically does not depend on the change in voltage U_{AC}.

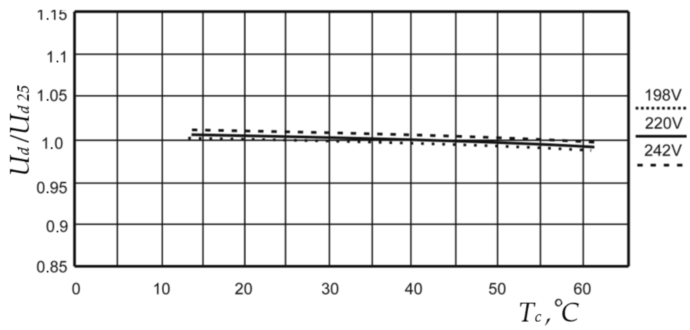


Figure 16. Dependencies of the relative voltage values U_d/U_{d25} on T_c temperature at 198 V, 220 V and 242 V supply voltage for Premier-10 lamp.

The luminous flux of the lamp decreases by 5% with increasing temperature (Figure 17), but not so significantly as it happens in the lamps with linear driver without current stabilization.

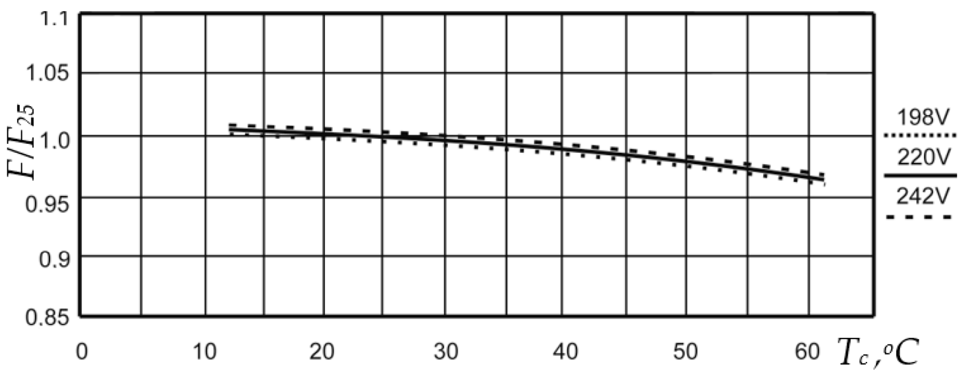


Figure 17. Dependencies of the relative values luminous flux F/F_{25} on T_c temperature at 198 V, 220 V and 242 V supply voltage for Premier-10 lamp.

This was explained by the fact that despite the ability of BP2863 chip to stabilize the output current also when the environment temperature changes, as it follows from its technical characteristics, the luminous flux of LEDs at current constant value still decreases with increasing temperature [11]. The current through LEDs, as well as the luminous flux of Premier-10 lamp, contains slight high-frequency pulsation (Figure 18).

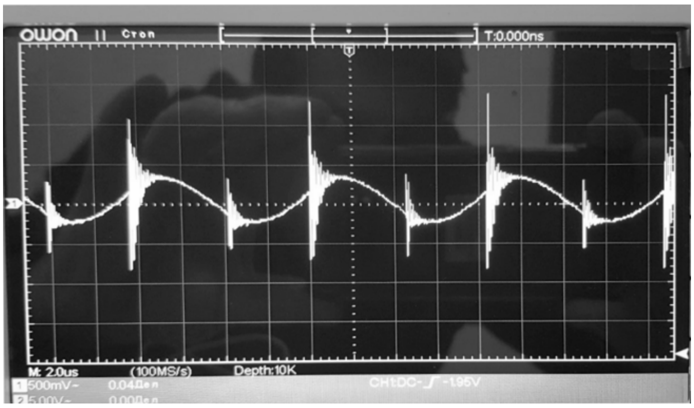


Figure 18. High-frequency current pulsation through LEDs of Premier-10 lamp.

In contrast to LED lamps, that works mainly under the conditions of temperature mode of residential premises (+15 . . . +30 °C), LED spotlights have higher power consumption and were used more often at environment temperatures. Let's consider their characteristics when the environment temperature changes at different values of supply voltage for different types of drivers.

2.3. Study of Temperature Dependence of Current and Luminous Flux of LED Spotlight SDO 06-20

Investigation of temperature dependence current and luminous flux of SDO 06-20 LED spotlight with power 20 W, scheme the control of which is built on high-voltage linear direct current LED driver. In the scheme, the compensating element (field-effect transistor) was connected gradually with LEDs. The driver contains built-in function of temperature compensation. The current was stabilized through LEDs.

The general view of LED matrix of the spotlight with electronic components was presented in Figure 19. The spotlight contains fourteen SMD 2835 LEDs with direct voltage 18 V, nominal current 50 mA and power 1 W [15]. Stabilization of the current was provided by two connected in parallel high-voltage stabilizers ICNE2521DE [19] (Figure 20).

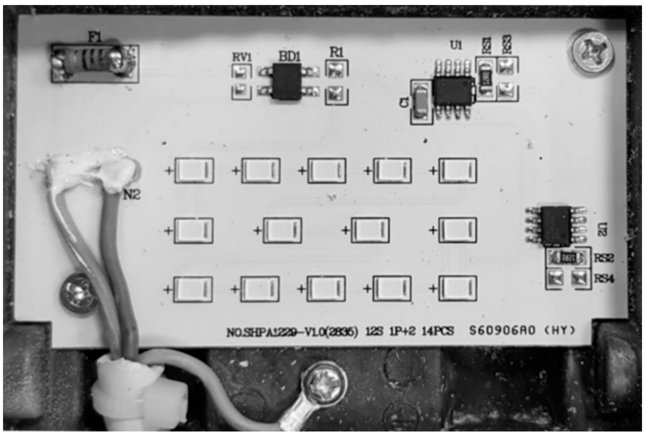


Figure 19. General view of the LED matrix of SDO 06-20 spotlight.

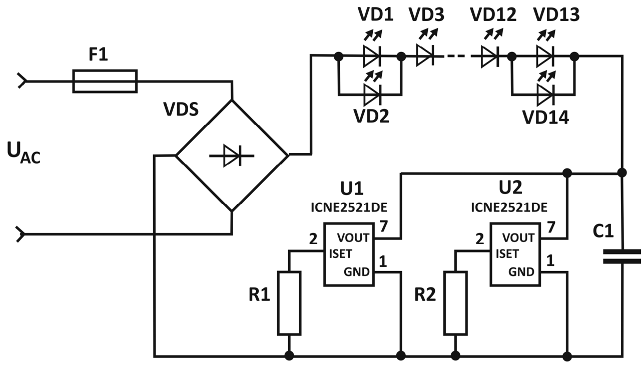


Figure 20. Principle electric scheme of SDO 06-20 spotlight.

The functional diagram of ICNE2521DE chip is shown in Figure 21.

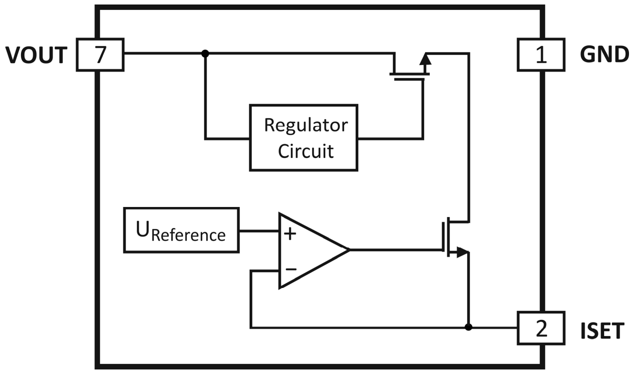


Figure 21. Functional diagram of ICNE2521DE.

As can be seen from Figures 20 and 21, the current of the spotlight LEDs was stabilized by the circuit—on ICNE2521DE microcircuit field-effect transistors were connected gradually. SMD-capacitor *C1* has small capacity and was used as high-frequency filter, therefore the voltage at the output of VDS diode bridge has the form of rectified sinusoid with 100 Hz pulsation frequency. Resistors *R1*, *R2* determine the amount of current through the spotlight LEDs.

The oscillogram of voltage on all spotlight LEDs gradually connected, which also has pulsating shape is represented in Figure 22, and current form through LEDs is shown in Figure 23.

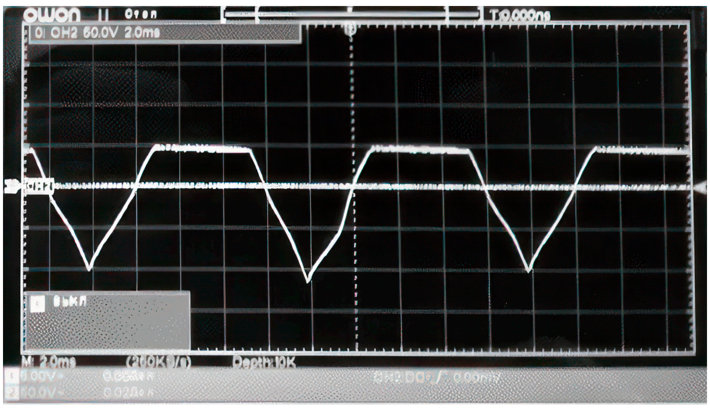


Figure 22. Voltage oscillogram of SDO 06-20 spotlight LEDs.

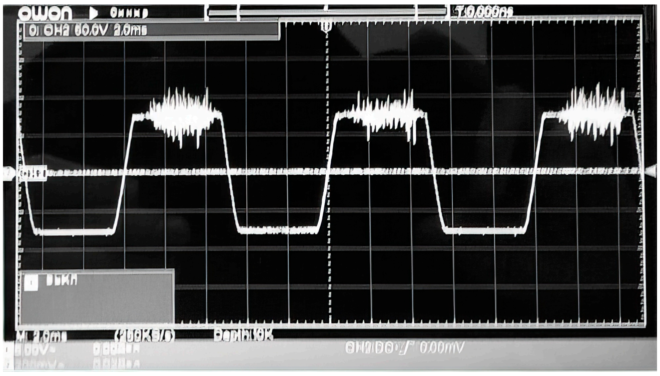


Figure 23. Oscillogram of the current through SDO 06-20 spotlight LEDs.

Current, like the spotlight luminous flux, has pulsating form with 100 Hz pulsation frequency.

Dependencies of the relative current values I_{inp}/I_{inp25} of SDO 06-20 spotlight on the environment temperature T_c at supply voltage 198 V, 220 V and 242 V were shown in Figure 24.

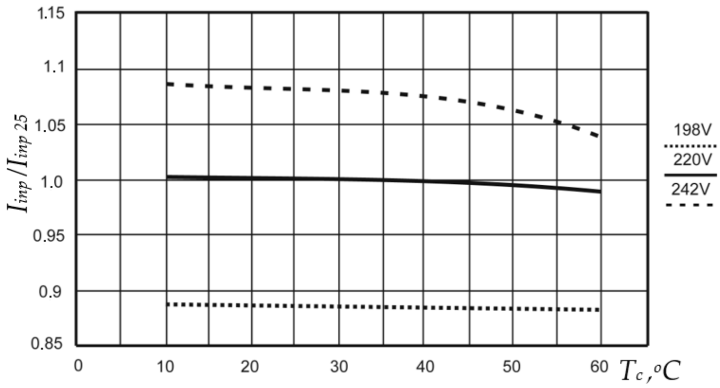


Figure 24. Dependencies of the relative current values I_{inp}/I_{inp25} of SDO 06-20 spotlight on the environment temperature T_c at 198 V, 220 V and 242 V supply voltage.

As can be seen from Figure 24, dependencies of the spotlight input current on the temperature increases with the increase of the supply voltage, and at 242 V, the current has the largest drop at the temperature higher than +40 °C.

Dependencies of the relative luminous flux values F/F_{25} of SDO 06-20 spotlight on the environment temperature T_c at supply voltage 198 V, 220 V and 242 V are represented in Figure 25.

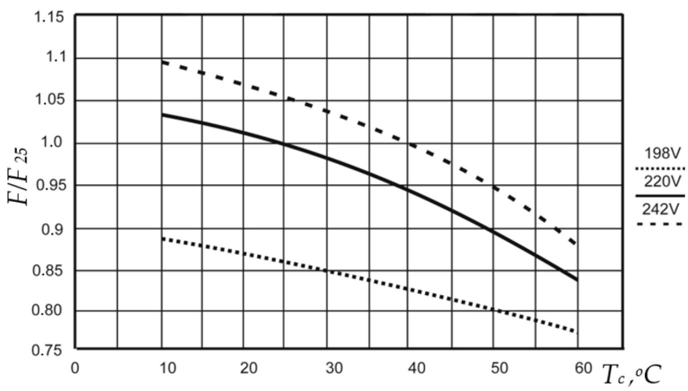


Figure 25. Dependencies of the relative luminous flux values F/F_{25} of SDO 06-20 spotlight on T_c temperature at198 V, 220 V and 242 V supply voltage.

The change in the spotlight luminous flux with temperature is quite significant (Figure 25) and increases with increasing supply voltage. Thus, at 198 V voltage, the drop of the luminous flux within +15 . . . +60 °C temperature range is 10%, and at 242 V voltage it increases up to 20%. Besides that, as was mentioned above, the spotlight has significant low-frequency current pulsations, and therefore the luminous flux, which could be avoided by means of low-frequency filter capacitor in the spotlight circuit after VDS diode bridge (Figure 20).

2.4. Investigation of the Temperature Dependence of Current and Luminous Flux of LED Spotlight Feron LL6020 LED

Let us consider the temperature dependence of current and luminous flux of TM Feron LL6020 LED spotlight with 20 W capacity, the driver of which is built according to the scheme of high-voltage direct current stabilizer based on BP2335 microcircuit. The external view of the spotlight LED matrix with electronic components was presented in Figure 26.

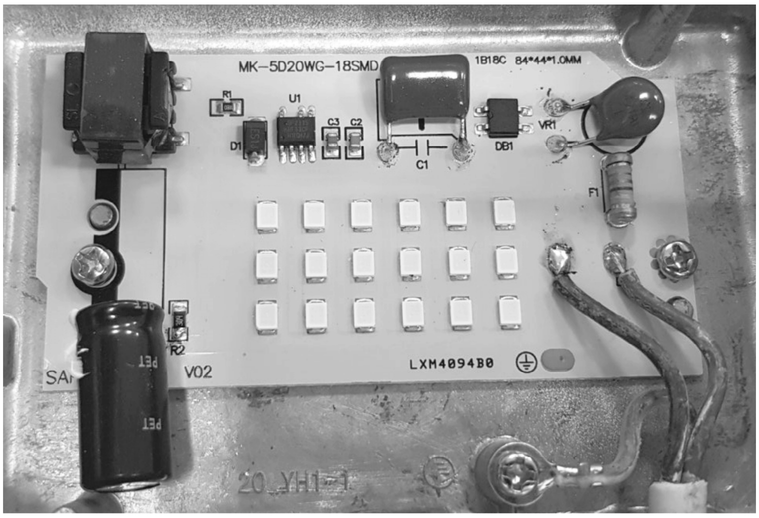


Figure 26. An external view of LL6020 spotlight LED matrix.

The spotlight contains eighteen SMD 2835 LEDs with direct voltage 12 V, nominal current 75 mA and power 1 W [17]. Current stabilization is provided by high-voltage direct current driver BP2335.

Principle electric scheme of the spotlight LL6020 is shown in Figure 27, and functional diagram of BP2335 chip is in Figure 28 [20,21]. The voltage after the circuit diode bridge VDS is fed to DRAIN input of BP2335.

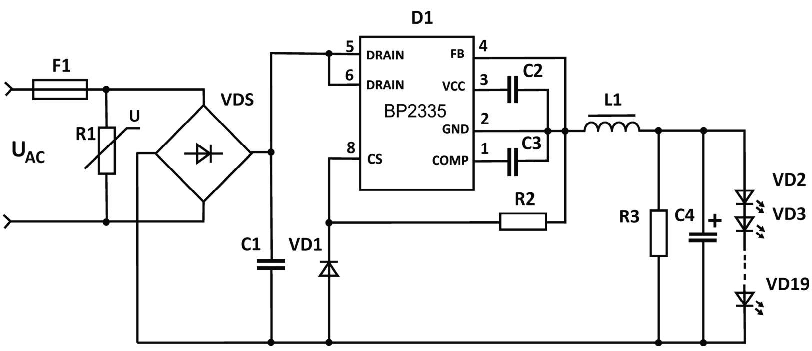


Figure 27. Principle electric scheme of LL6020 spotlight.

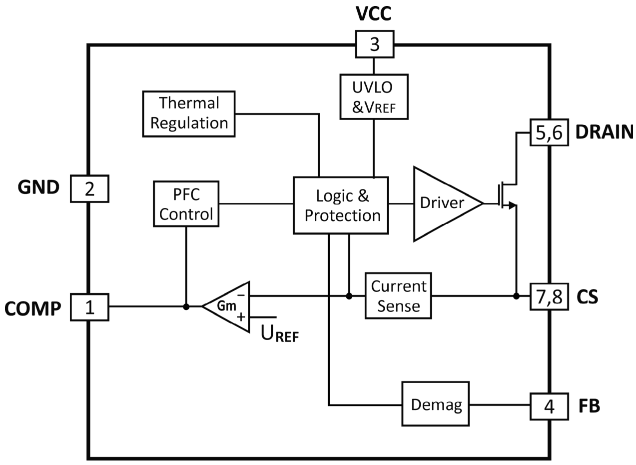


Figure 28. Functional diagram of BP2335.

Voltage from CS output, modulated by high-frequency signal (frequency 40 ... 45 kHz) was served to *L1C5* filter elements. LEDs were connected to this filter gradually. Chip line FB is the input of feedback union by the LEDs current (Figure 28).

The principle of signal formation at CS output of the chip was shown in Figure 29, and the oscillogram of this voltage is in Figure 30.

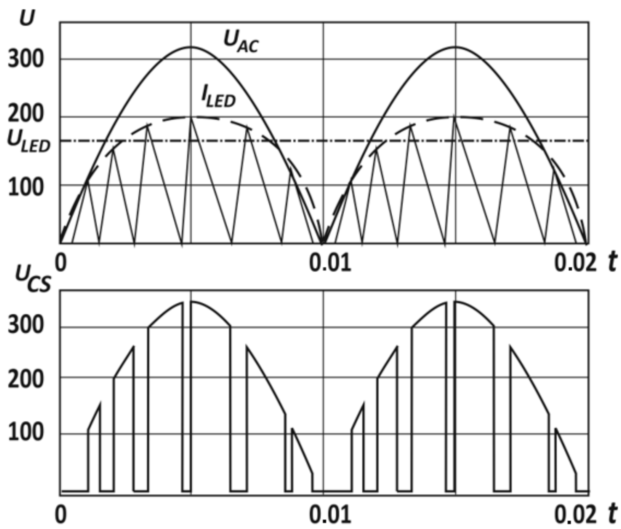
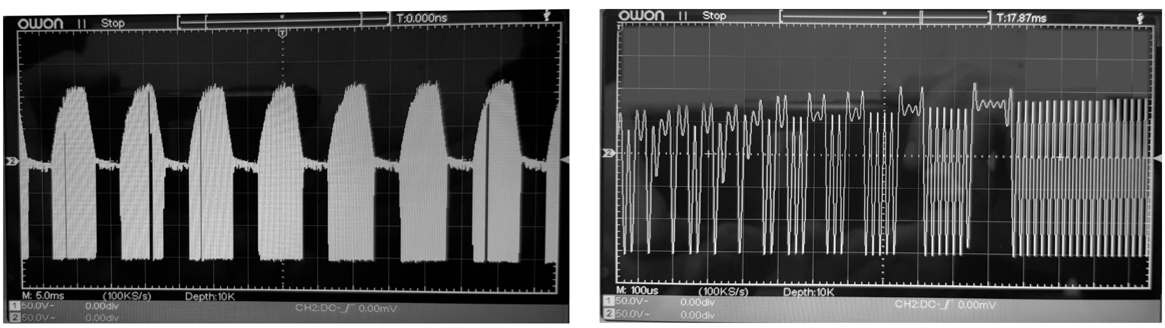


Figure 29. Voltage formation at CS output of BP2335.



(**a**) (**b**)

Figure 30. Voltage oscillogram at CS output (**a**) and its scanner in the time (**b**).

LL6020 spotlight has small low-frequency pulsation of the current through LEDs, on which the harmonics of high-frequency component are covered (Figure 31).

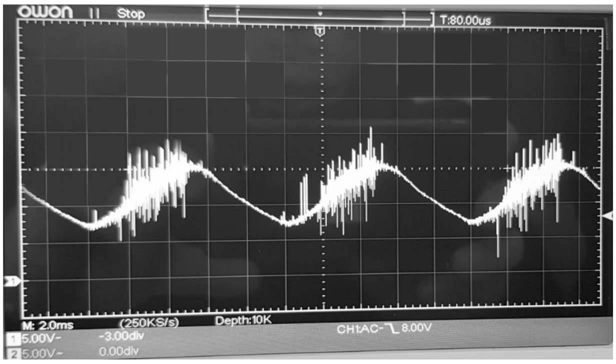


Figure 31. Current pulsation of LL6020 spotlight.

Dependencies of the relative current values of I_{inp}/I_{inp25} of LL6020 spotlight on temperature T_c at supply voltage 198 V, 220 V and 242 V are presented in Figure 32.

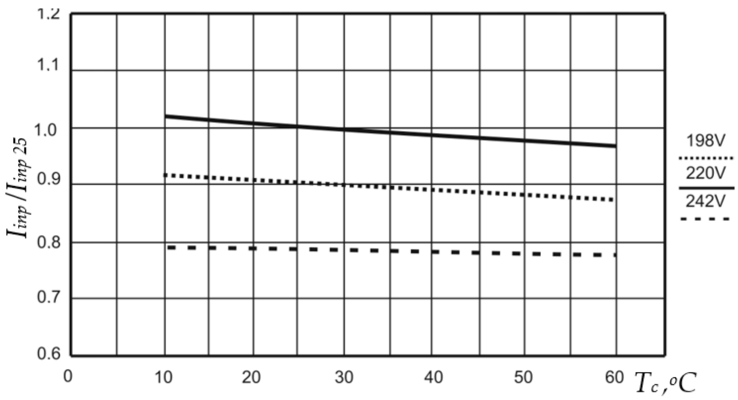


Figure 32. Dependencies of the relative current values I_{inp}/I_{inp25} of LL6020 spotlight on temperature T_c at 198 V, 220 V and 242 V supply voltage.

Dependencies of the relative values luminous flux F/F_{25} of LL6020 spotlight on temperature T_c at supply voltage 198 V, 220 V and 242 V were shown in Figure 33.

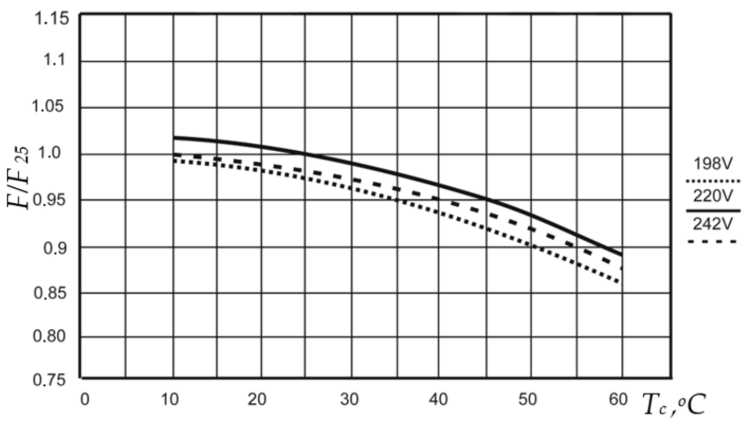


Figure 33. Dependencies of the relative luminous fluxes values F/F_{25} of LL6020 spotlight on temperature T_c at 198 V, 220 V and 242 V supply voltage.

If the input current of the spotlight (Figure 33) changes within small limits with increasing temperature at different values of the supply voltage, then the luminous flux within the temperature range +15 . . . +60 °C decreases by more than 10%, which is due to the effect of temperature on LEDs parameters.

3. Results and Discussions

3.1. Validation with Experiment Results

The proposed approach to the change of driver design for compensation of luminous flux alternation of LED light source at the environment temperature changes.

For further analysis, let us use the characteristics of LEDs, which are freely available in the form of graphical or tabular data of most manufacturers of LED products.

Let us review the dependence of direct voltage on U_d LED on temperature T_c at constant (nominal) current value $I_{d\ nom}$ (Figure 34) and dependence of the relative luminous flux value F/F_{25} of LED on the temperature T_c (Figure 35) [12].

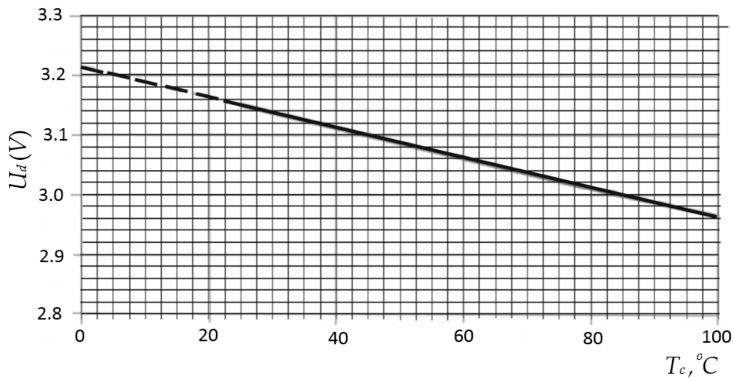


Figure 34. Dependence of direct voltage U_d (V) of the SMD2835 LED on the temperature T_c at nominal current value $I_{d\ nom}$.

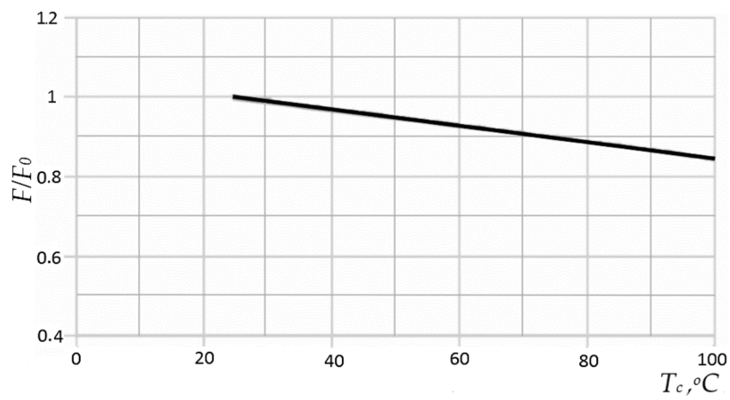


Figure 35. Dependence of the relative luminous flux value F/F_{25} of SMD2835 LED on the temperature T_c.

Characteristics of SMD2835 LED with voltage 3 V were shown in Figures 34 and 35. LEDs with 6 V, 9 V, 12 V, 18 V and higher voltages, which were used mainly in LED lighting devices, are the design of LEDs gradually connected with voltage 3 V located in one SMD-case [22–26]. Therefore, we can consider the characteristics shown in Figures 34 and 35, given to relative values, as fair for other LEDs of this type Let's build the dependence U_d on temperature (Figure 34) in relative values, that is, as U_d/U_{d25} on T_c, where U_{d25} is voltage on LED at T_c = +25 °C (Figure 36).

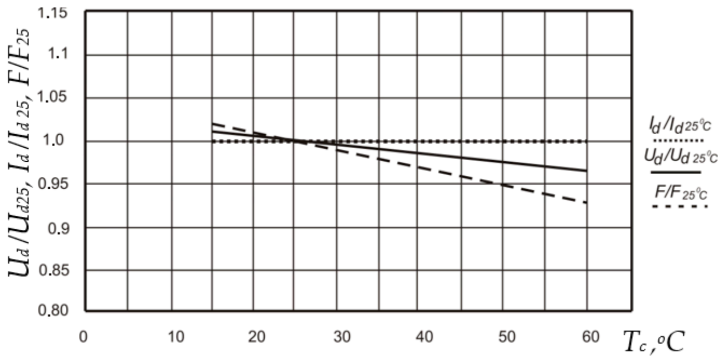


Figure 36. Dependenices of the relative values U_d/U_{d25}, I_d/I_{d25} and F/F_{25} on temperature T_c for SMD2835 LED, I_d = *const*.

In the same graph, we will show the dependence of the relative value of the luminous flux F/F_{25} on temperature T_c. The amount of current through LED is constant and equal to its nominal value $I_{d\ nom}$. On the graphs I_{d25}, F_{25} were relevantly the nominal current and luminous flux of the LED at +25 °C. It is evident from Figure 36 that current stabilization through the LED does not ensure the stabilization of its luminous flux with ambient temperature changes.

But, if you maintain constant voltage on LED, the drop in luminous flux should not be so significant (Figure 37).

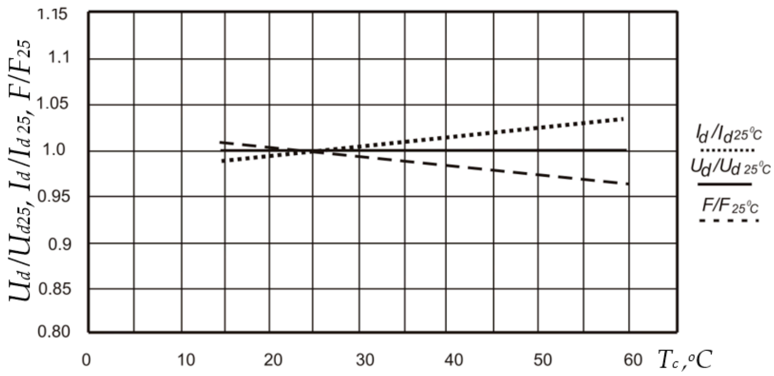


Figure 37. Depenence of the relative values U_d/U_{d25}, I_d/I_{d25} and F/F_{25} on temperature T_c for SMD2835 LED, U_d = *const*.

That means, voltage drop on the LED can be used as temperature sensor during LED lighting device operation, without maintaining constant current through it.

Let us give the quantitative estimate of LED current and its luminous flux changes depending on the environment temperature in case when voltage on the LEDs is constant.

Dependencies given in Figure 37, are linear within temperature range +15 . . . +60 °C, so we will use the linear approximation of the characteristics for the case when voltage on LEDs is U_d = *const*.

The expression for dependencies of the relative values of current I_d/I_{d25} on temperature T_c (Figure 37) is as follows:

$$I_d/I_{d25} = 0.97 + 0.0013\ T_c, \tag{3}$$

or

$$I_d = I_{d25}\ (0.97 + 0.0013\ T_c), \tag{4}$$

where I_{d25} is nominal value of LED current at +25 °C.

In order to approximate the dependence of the relative values of the luminous flux on the environment temperature (Figure 37), let us use the linear approximation (3).

$$F/F_{25} = 1.025 - 0.001\ T_c, \quad (5)$$

or

$$F = F_{25}(1.025 - 0.001\ T_c). \quad (6)$$

Dependencies (3) and (5) make it possible to estimate the change in current through SMD2835 LEDs and their luminous flux as a part of LED light sources when the environment temperature changes within temperature range +15 . . . +60 °C.

3.2. Advantages and Disadvantages of the Proposed Approach to the Temperature Effect Compensation

The advantage of this approach concerning the implementation of the driver for LED light source in terms of the output voltage stabilization at the environment temperature changes are the ability to reduce the drop of the LED device luminous flux when the environment temperature increases.

The disadvantage is that, at the same time there is no complete stabilization of the luminous flux when the environment temperature changes.

4. Conclusions

The study of linear drivers of LED devices without current stabilization showed that they do not provide stabilization of the light flux when the ambient temperature changes at a constant value of the voltage of the power supply network, although the current of the LEDs at a constant voltage practically does not change with the temperature change.

When the supply voltage changes, both the current strength and the luminous flux of the LEDs receive significant changes with increasing temperature and in the temperature range +15 . . . +60 °C at a voltage of 198 V is up to 8%, at a voltage of 220 V—up to 13%, and at 242 V—up to 17%.

Studies of LED devices with drivers that provide stabilization of the current of the LED light source when the supply voltage and ambient temperature change have shown that, in this case, the stabilization of the light flux doesn't happen. The luminous flux decreases from 10 to 20% when the temperature changes in the range of +40...+60 °C, depending on the type of driver.

When researching drivers with current stabilization due to PWM modulation of the output voltage, it turned out that only they are the most stable in terms of electrical and light parameters. When the temperature increased to +60 °C, the luminous flux of LED devices with such drivers decreased by only 5%.

According to the results of the conducted research, it is proposed to perform LED light source drivers with stabilization of not the current, but the voltage on the LEDs, which would allow to reduce the drop in the luminous flux of the LED device when the ambient temperature increases compared to the drivers of LED devices built according to the current stabilizer scheme.

It is proposed to evaluate the change in the main electrical and light parameters of the LED lighting device when the ambient temperature changes, to use the characteristics given in the documentation for one or another type of LEDs, namely—the dependence of the constant voltage of the LED on the temperature at a constant value of the current and the dependence of the relative value of the luminous flux of the LED from temperature.

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