

Development of Headlight System with Cost Advantageous Design Using Light Emitting Diodes

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ABSTRACT

Recently, it is widely noticed that replacing conventional incandescence lights with light emitting diodes as light sources is beneficial in terms of their low power consumption, longer life and larger degree of freedom in designing. That is also the case in automobile industry and light emitting diodes are increasingly used as light sources. Applying light emitting diodes to light sources of the headlights, which consume a large amount of electric power, is highly advantageous for overall reduction of consumed energy in a vehicle resulting in a good fuel economy. Moreover, if light emitting diodes are applied to headlights of motorcycles sold in a large number in affordable price range, a significant contribution is expected to the reduction of the total amount of carbon dioxide emission. However, up to the present, the use of light emitting diodes for headlights of motorcycles has been limited to only certain models in high price range. This is mainly because the headlight systems using high power light emitting diodes and their driver units are expensive. Based on these backgrounds, we adopted a configuration with a multiple use of medium intensity light emitting diodes. In addition, heat dissipation configuration that fulfills the thermal requirements was devised without using a heat sink that was a causal factor of high cost. The cost was further reduced through the employment of a single constant current regulation circuit. It was made possible by the serial connection of high-beam and low-beam light sources. This development made it possible to employ headlights using light emitting diode for motorcycles in low price ranges as well.

1. Introduction

Light Emitting Diodes (LEDs) are drawing attention these days because of the various advantages, compared to incandescence light sources, such as small power consumption, long lives and a large degree of freedom in exterior designing and structural designing. In addition, they discharge little amount of hazardous chemical substances when recycled.

Lighting appliances using LEDs are getting widely spread. The amount of shipment of LED lighting devices is increasing with the rise of energy saving consciousness strongly enhanced after the disaster of the Great East Japan Earthquake. With that trend, the price of LED has been reducing and is getting into a status of the vast use (Fig. 1)⁽¹⁾.

Because of the same advantages mentioned above, LED light sources are getting a wide use in automobile industry as well through applications to lighting devices, indicators for alert and/or display and lightings in cabin. Recently, LED light sources are extensively applied to the lighting devices. Among those, headlights especially consume a large power. Accordingly, adoption of LED light sources to headlights significantly contributes to a reduction of the

power consumption. Thus, it results in a large contribution to the reduction of total consumed power of a vehicle improving the fuel economy as a consequence. A large contribution to the reduction of the global CO₂ emission is anticipated if the application of LED light sources is expanded to be applicable to motorcycles sold in a large number in a range of reasonable price. In the first place, headlights using LED light sources

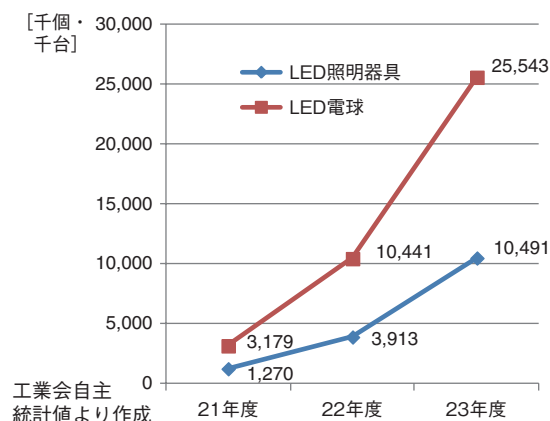


Fig. 1 Numbers of shipments of LED products

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were applied to automobiles in 2007, and the first application to a motorcycle was in 2012. However, a conventional LED headlight system has an issue of high cost because the components, such as a heat sink and a driver circuit, are necessary to be added to a conventional incandescent lamp based system. That cost increase is illustrated in Fig. 2 showing the case that a conventional LED headlight is applied to a low priced range commuter type motorcycle.

As shown in the figure, the cost of a LED headlight system is approximately four times larger than that of an incandescent lamp based system, and its application to a commuter type motorcycle seems extremely challenging. To resolve this issue, an examination of possibilities to reduce the cost of a LED light source system and the driver, which were especially costly, was conducted. To dissipate the heat generated by LED, the addition of a heat sink is needed and is the primary cause of the high cost of the light source system. The heat dissipation using a heat sink is inevitable in a system applying conventional technologies because of large power consumption by a LED. Consequently, it was tried in our development to eliminate the heat sink for reducing the cost of LED headlight system.

The second reason for the high cost of the LED light source system was that it was necessary to have a separate control circuit for each of the low beam (Lo) and the high beam (Hi). In this development, it was tried to reduce the cost of LED headlight system by simplifying the control circuits with a change of the electrical connections of LEDs for the high beam and the low beam.

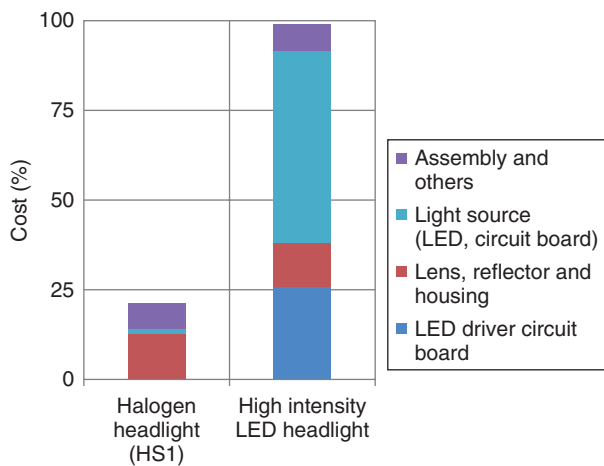


Fig. 2 Cost constituents of a halogen headlight system and a conventional LED headlight

2. Study of Feasibility of LED Headlights without Heat Sinks

2.1. Study of Potential for Use of High Intensity LEDs

First, the research considered the potential for the reduction of the heat sinks in headlights using conventional

Table 1 Rated values of performances for high intensity LED and halogen light bulb

Specification	High intensity LED (PHILIPS/ALTION) ^{*(1)}	Halogen (HS1)
Luminous flux	800 lm	825 lm (High)
Rated voltage	13.7 V	13.2 V
Rated current	1.0 A	2.65 A
Rated power	13.7 W	35 W

^{*(1)} The performance as of products in 2010

high intensity LEDs for automotive use. Tests were conducted using HS1 bulbs, which are used extensively in low-cost two-wheeled vehicles for markets in developing countries (commuters), and high intensity LEDs, both of which provide the same level of luminous flux. Table 1 shows a performance comparison of high intensity LEDs and HS1 bulbs.

In order to study whether heat dissipation would be possible without the use of heat sinks, high intensity LEDs were mounted on glass epoxy substrates (Flame Retardant Type 4: FR4), and the relationship between the LED current and the temperature of the LED joint sections (T_j temperature) was measured (Fig. 3). Substrates of 130 mm in width and 50 mm in depth were used for both high beam and low beam LEDs to produce a size able to be positioned within an incandescent bulb headlight. The substrates were two-sided, coated with a copper foil of 35 μm in thickness. The surface area of the copper foil was identical on both sides of the substrates, and was 14,300 mm^2 in total for both sides. The copper foil was run through through-holes in order to help ensure heat conduction between the foil on each of the sides of the substrates. Ambient temperature was set at the upper limit for the temperature of the use environment for automotive lights. For the measurement of T_j temperatures, the temperature of the solder connection on the cathode sides of the LED chips (T_s) was measured using thermocouples, and the amount of heat from T_s to T_j was calculated by adding the power impressed on the LED (LED forward

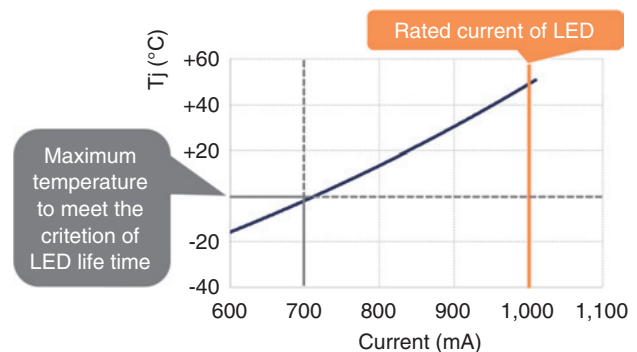


Fig. 3 Characteristic of high intensity LED under the heat dissipation condition without heat sink

Table 2 Rated values of performances for high intensity LED and medium level intensity LED

Specification	Medium intensity LED	High intensity LED
Luminous flux	200 lm	800 lm
Rated voltage	3.0 V	13.7 V
Rated current	700 mA	1.0 A
Rated power	2.2 W	13.7 W

voltage x operating current) to heat resistance inside the LED.

When the drive current is larger than 700 mA, T_j of high intensity LEDs exceeds the maximum operating temperature that can guarantee the life time requirement, which is determined by intensity deterioration characteristics. Consequently, it was verified that the heat dissipation requirement could not be met without a heat sink. These results demonstrated that when high intensity LEDs were employed, it would not be possible to realize the functions of a headlight without the use of heat sinks.

2.2. Study of Feasibility of Application of Medium Intensity LEDs

As indicated in the preceding section, it would not be possible to employ high intensity LEDs without using heat sinks. The potential for the use of multiple medium intensity LEDs instead of high intensity LEDs and the realization of heat dissipation performance by means of a dispersed arrangement of the LEDs (the heat sources) was, therefore, examined. Table 2 and Fig. 4 show representative rated performance values for medium intensity LEDs.

While high intensity LEDs are exclusively used as light sources for automotive headlights, medium intensity LEDs are employed as light sources in a wide variety of consumer applications in addition to their use in

automotive daylight running lamps. As such, they are manufactured in higher quantities than high intensity LEDs, and their cost is being reduced. Because of this, based on consideration of the cost of individual LEDs, the use of multiple medium intensity LEDs could reduce the cost of the light source when compared to the use of high intensity LEDs. Figure 5 shows the relationship between luminous flux and cost for high intensity and medium intensity LEDs.

Luminous flux when high beam is used is approximately 800 lm, and the cost of realizing this level of brightness using medium intensity LEDs is approximately half that when a high intensity LED is employed. It is necessary to use four medium intensity LEDs in order to realize a luminous flux of 800 lm. Two medium intensity LEDs are lit for low beam; by activating a further two LEDs in addition to the low beam light sources when using high beam, it would be possible to obtain a luminous flux equivalent to that of an HS1 bulb. In addition, the rated power of a medium intensity LED is 2.2 W, less than one-sixth the rated power of a high intensity LED. Therefore, it would be possible to realize adequate heat dissipation using a small substrate when four medium intensity LEDs were employed.

Next, the potential for heat dissipation without the use of heat sinks when medium intensity LEDs were employed was examined. Four FR4 substrates with different copper foil area to mount the medium intensity LEDs, were measured for each of T_j temperature. In the above test, T_j of LED is confirmed the copper foil area less than the temperature that can guarantee the life time requirement, which is determined by intensity deterioration characteristics. The substrates were FR4 two-sided substrates. The thickness of the heat-dissipating copper foil was 35 μm , and the foil was the same size on both sides of the substrates. The copper foil was run through through-holes to help ensure heat conduction between the two sides of the foil. The method described above was employed for the measurement of the T_j temperature.

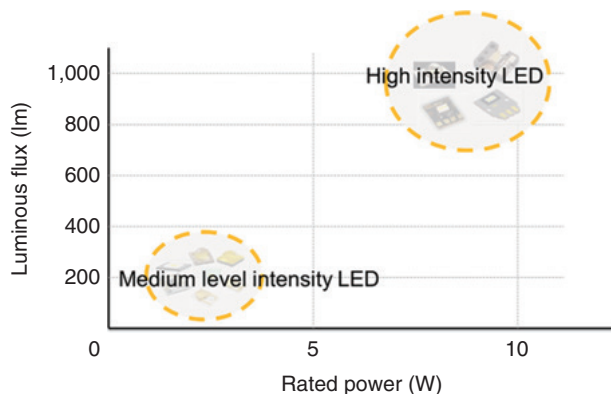


Fig. 4 General ranges in the diagram of rated power and luminous flux for high intensity LEDs and medium level intensity LEDs

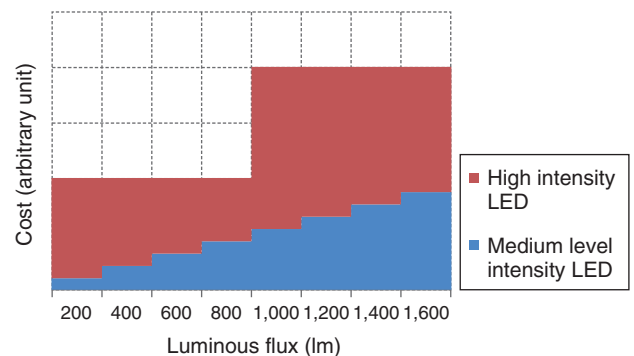


Fig. 5 Relationship between luminous flux amplitude and cost for high intensity LED and medium level intensity LED

Figures 6 and 7 show images of substrates mounted with medium intensity LEDs.

The current flowing to the LEDs was 700 mA, and the ambient temperature was set at the upper limit of the temperature of the use environment of the lights. Fig. 8 shows the relationship between the LED T_j and the surface area of the copper foil on the substrate.

The results indicated that if it was possible to obtain a total surface area of 2,000 mm² (total for front and rear) for the heat-dissipating copper foil for each medium intensity

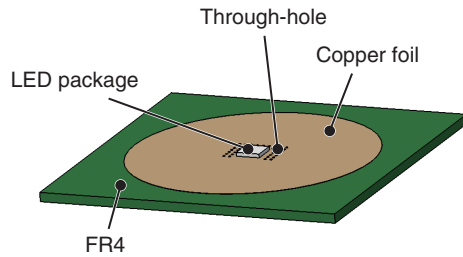


Fig. 6 Schematic view of onboard medium level intensity LED

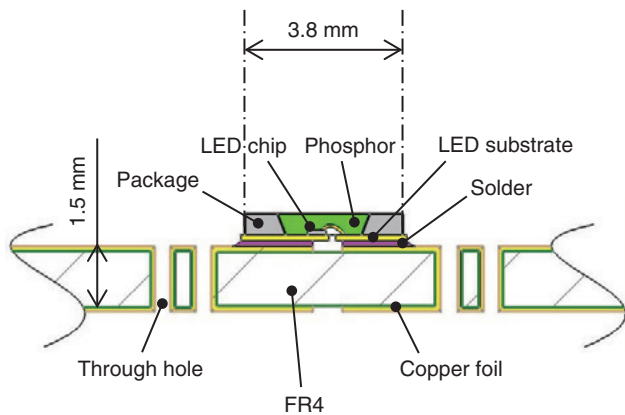


Fig. 7 Circuit board mounted with LED of medium level intensity (cross-sectional view)

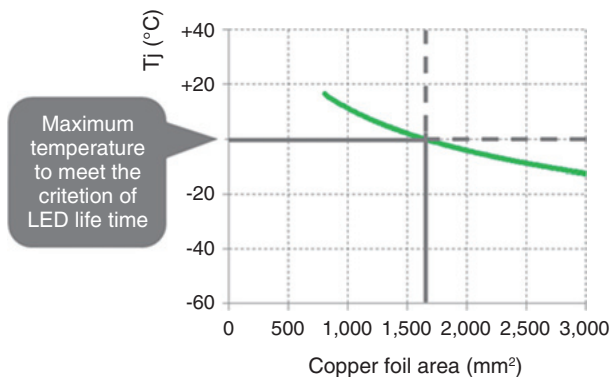


Fig. 8 Heat dissipation characteristic of a medium level intensity LED without heat sink

LED (power: 2.2 W), it would be possible to realize a light without the use of heat sinks. In addition, it was possible to use substrates of 130 mm in width and 50 mm or less in depth for both low beam and high beam. This size is within the size employed in the headlights of commuter models. These results demonstrated that it would be possible to fulfill headlight functions without the use of heat sinks by employing multiple medium intensity LEDs.

3. Study of Feasibility of High Beam/Low Beam Series Connection Activation Circuit

The activation circuits of conventional LED headlights use 12 V batteries as power sources; the LED light source and a high beam circuit provided with a constant-current regulator circuit and a similarly equipped low beam circuit are connected in parallel. Figure 9 shows LED headlight activation circuits connected in parallel.

By contrast with a series connection, when a parallel connection is employed, variations in the value of the current flowing to each row of LEDs occur, and the current flowing fluctuates when switching from activating one row of LEDs to activating two rows of LEDs. This makes it necessary to provide each row of LEDs with a constant-current regulator connected in parallel. In the case of a series connection, there are no variations in the current flowing to each LED and the current flowing is constant. A series connection thus presents the advantage of making it possible to use only one constant-current regulator. However, because V_f is high in the case of a series connection, it is necessary to supply a high voltage, and therefore to address issues including the method of switching between low beam and high beam circuits and of responding to LED malfunctions. Table 3 compares parallel and series connections.

3.1. Method of Realization of High-voltage Drive without Booster Circuit

The maximum V_f of the medium intensity LEDs discussed in the previous section was 3.5 V, while a voltage of 14 V or higher is necessary for activating the LEDs when two low

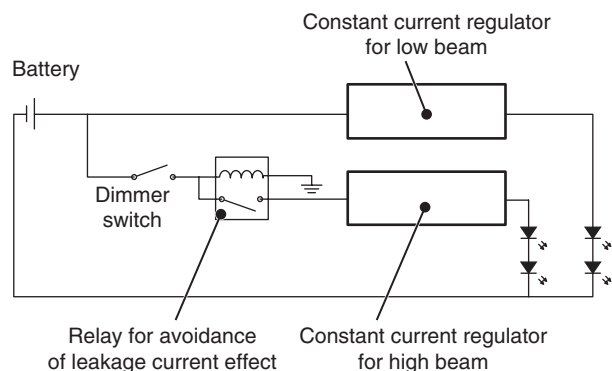


Fig. 9 Schematic circuit diagram for turning on the conventional headlights

Table 3 Comparison between parallel and series circuit connections

Wiring	Parallel connection	Series connection
Equivalent circuit		
Current variation and associated measures	Separate current regulations are necessary because unbalanced current supply occurs from the difference in V_f of those LEDs if one common regulation circuit is applied for providing currents to both of the LEDs for low and high beams.	The same magnitude of current flows through both of low and high beam LEDs.
Constant current circuit	Two (necessary for each line)	One
Total drive current	Large total current is needed for supplying two lines. (1,400 mA)	Current is the same as when driving one LED and unchanged with the number of LEDs. (700 mA)
Drive voltage	Driven by relatively low voltage with a small number of LEDs connected in series on each line. (The voltage is deliverable by using only a down converter.)	V_f becomes high in association with the number of LEDs.
High/Low alternation	By placing on/off switch onto the high beam circuit line, high and low beams alternation is possible.	Placing on/off switch onto the series-connected line works only for turning on or off for both beams at the same time.
When one LED fails in open mode	The other beam with unflawed LED can be turned on.	Both beams cannot be turned on.

beam LEDs and two high beam LEDs are connected in series. Because of this, it is necessary to use a booster circuit when employing a battery as the power source. It was therefore decided to use an ACG, which have long been extensively used in the incandescent bulb headlights of commuter models, as a power source and regulate negative voltage half-waves in order to make it possible to employ the type of circuit that supplies 12 V to incandescent bulb headlights.

Conventional incandescent bulb headlight activation circuits control the voltage impressed on the bulb via the effective voltage of the ACG AC negative voltage half-waves.

By outputting the thyristor (SCR) timing signal (Trig) with consideration of the discrepancy between the preset voltage and the results of calculation of the effective voltage, it is possible to control the period for the supply of power and obtain a constant effective voltage. Figures 10 and 11 show circuits for incandescent bulb headlights that apply negative voltage half-wave activation.

In the case of an LED, constant-current control is necessary. To realize this, the specifications were modified against the incandescent bulb headlight system circuit to make it possible to monitor the current flowing to the LED and control the period of power supply to a thyristor. The use of ACG negative voltage half-waves for constant-current

control would produce concerns over flickering of the LED. Unlike incandescent bulb headlight system, LEDs do not display an afterglow, and because of this flickering due to pulsating current tends to be more conspicuous in LEDs than in incandescent bulbs. The research team decided to attempt to control this flickering by means of the standard method

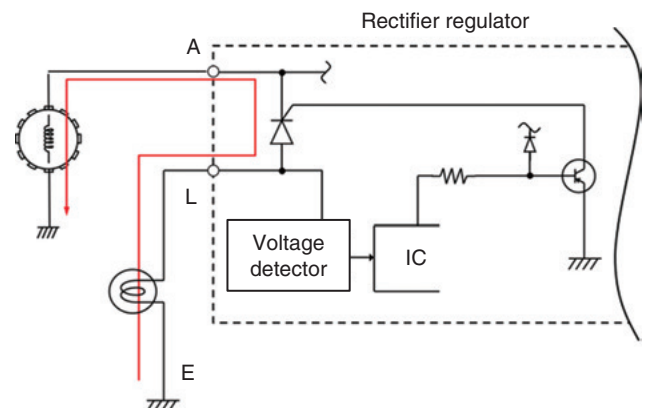


Fig. 10 Circuit diagram of halogen headlamp driver applying negative voltage half wave activation type

of employing a capacitor in order to smooth the pulsating current, but this presented the twin issues of determining the necessary capacitance of the capacitor for control of flickering and the development of a method of controlling voltage to below the withstand voltage of the capacitor.

In order to determine the necessary capacitance of the capacitor, it was first necessary to determine a benchmark for the allowable level of flickering. The present research aimed to realize a level of flickering equivalent to or lower than that realized by the ACG negative voltage half-wave activation method employed for conventional incandescent bulb headlights.

The results of tests to realize a level of flickering equivalent to that of a conventional incandescent bulb headlight showed that LED flickering could be controlled to an equivalent or lower level at ripple currents of 300 mA or below. The results of tests of ripple current with changes in the capacitance of the capacitor showed that at 2,250 μF and above, the ripple current was 300 mA or below, but below 2,250 μF , ripple current increased rapidly. Taking variations of $\pm 20\%$ and an assumed level of capacitor degradation of -20% into consideration, a figure of 4,800 μF was set as the necessary capacitance to help ensure that capacitance did not fall below 2,250 μF . Figure 12 shows the ripple current characteristic in relation to the capacitance of the capacitor.

Because no current would flow to the LEDs when the LED headlights were turned OFF, the voltage from the ACG would continue to rise, overshooting the withstand voltage of the capacitor and resulting in its malfunctioning.

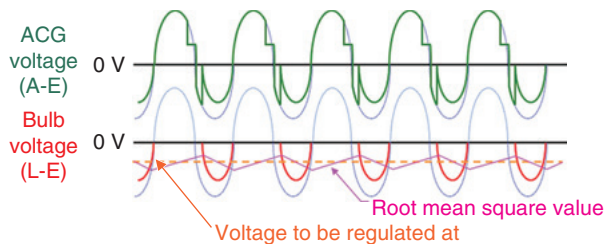


Fig. 11 Waveforms of halogen headlamp driver applying negative voltage half wave activation type

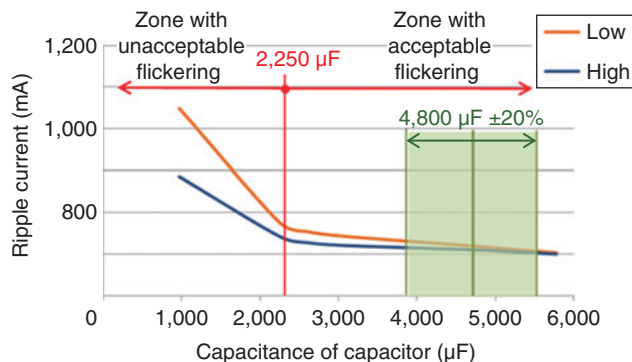


Fig. 12 Ripple currents to capacitance

To respond to this, a benchmark voltage lower than the rated voltage of the capacitor was set, and a control circuit was added that would output a timing signal to reduce the amplitude of thyristor power and adjust the voltage to below the benchmark voltage when voltage increased in excess of the benchmark. Because a capacitor with a rated voltage of 25 V was selected, the benchmark voltage was set at 21 V, taking variations in capacitor temperature characteristics and other factors into consideration. Figures 13 and 14 show the constant-current control circuit with the added capacitor.

During the negative current cycle, the thyristor is ON, and the electrolytic capacitor accumulates potential at the same time as power flows to the LEDs. During the positive current cycle, discharge current flows from the electrolytic capacitor to the LEDs via the current detection circuit.

The current detection section monitors the current flowing to the LEDs. At the same time, the voltage detection section monitors the voltage at both ends of the electrolytic capacitor. If any of these figures exceed benchmark values, Trig is output to reduce the amplitude of the power supply to the thyristor; if any are lower than benchmark values,

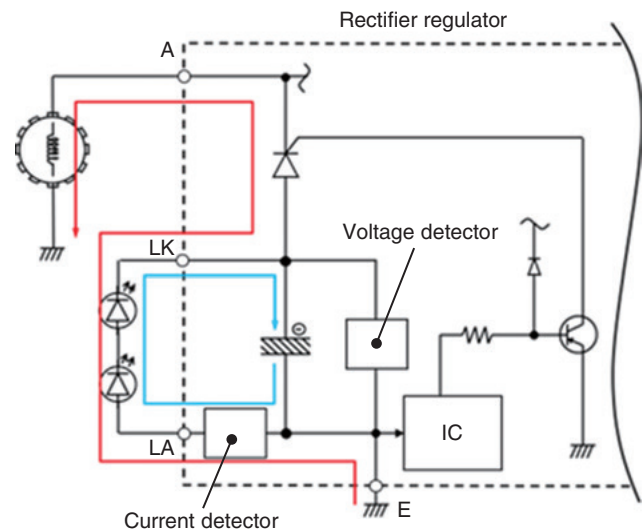


Fig. 13 Circuit diagram adopted with capacitor

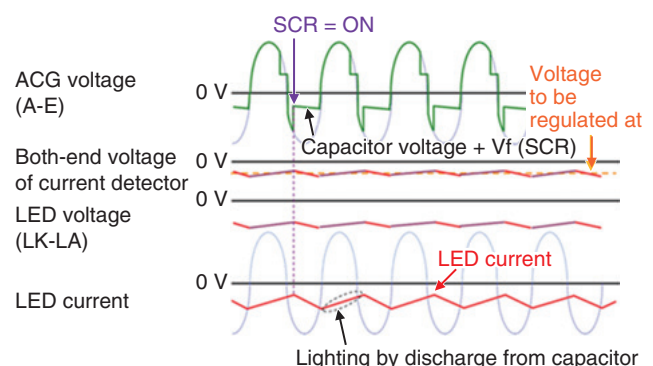


Fig. 14 Waveforms in the circuit adopting capacitor

Trig is output to increase the amplitude of power supply to the thyristor. When current is flowing to the LEDs, current is monitored and constant-current control is employed as the method of output control. When no current is flowing to the LEDs due to a disconnected wire or other factor, the voltage at both ends of the electrolytic capacitor is monitored, and constant-voltage control is employed as the output control method.

3.2. Method of Switching between High Beam and Low Beam using Series Circuits

With regard to the form of LED activation, when the headlights are used on low beam, only the two LEDs on the low beam side are activated; when the headlights are switched to high beam, the two LEDs on the low beam side and the two LEDs on the high beam side are activated simultaneously. In other words, the LEDs on the low beam side are always activated, and switching between low beam and high beam is effected by activating or deactivating the LEDs on the high beam side. Therefore, the bypass line was provided from the middle part of the low beam LEDs and the high beam LEDs in parallel with the high beam LEDs. Alternation circuit of low and high beams is carried out by dimmer switch on the bypass line. Figure 15 shows the circuit that switches between low beam and high beam.

To prevent mistaken activation of the LEDs on the high beam side when the dimmer switch is infiltrated by water, LED headlights using conventional parallel connections are provided with waterproof switches, or they use non-waterproof switches and employ a relay to remove leak current or incorporate a leak current detection circuit in the driver. Any of these measures results in increased cost. In the case of the circuit employed in the developed system, even if the dimmer switch leaks when the high beam is not activated, the circuit will not produce mistaken activation of high beam. In addition, if a leak occurs when high beam is activated, the brightness of the LEDs is dimmed because the current on the high beam side decreases by the amount of current flowing to the bypass circuit, but because the current flowing due to the leak is miniscule, the effect cannot be seen by the naked eye.

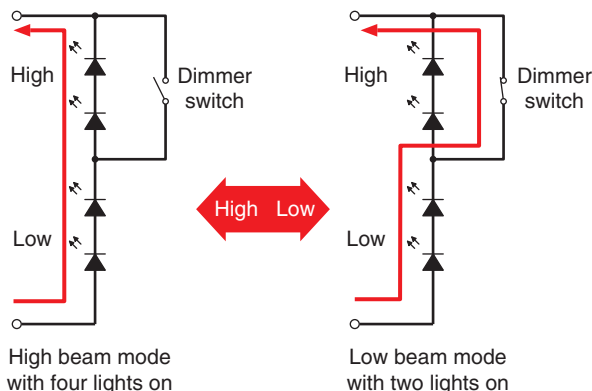


Fig. 15 Alternation circuit between low and high beams

The application of the developed circuit, therefore, makes it possible to reduce the use of countermeasures for dimmer switch leaks, which have conventionally been necessary. However, the use of the method did newly necessitate the application of a countermeasure against rush current occurring when switching from high beam to low beam.

When switching from high beam (four LEDs) to low beam (two LEDs), the capacitor maintains V_f for four LEDs. This results in a rush current when switching to two LEDs. To respond to this phenomenon, a transistor was added to the configuration and a rush current limit resistance was set, and a limiting circuit was employed that produces a current via a resistance only when a rush current occurs. At the normal 0.7 A of constant current control, the base current flows to the transistor Q1, and Q1 is ON; in this state, no current flows to the resistance Rs2 (Fig. 16).

When high beam is switched to low beam, if a current of 1.0 A or greater flows, the voltage between terminals Rs3 increases, and the voltage of Dr1 and Dr2 becomes lower than that of Q1 and Rs3. Because of this, the base current stops flowing to Q1, and Q1 switches OFF. As a result, current flows to resistance Rs2, and the rush current is restricted (Fig. 17).

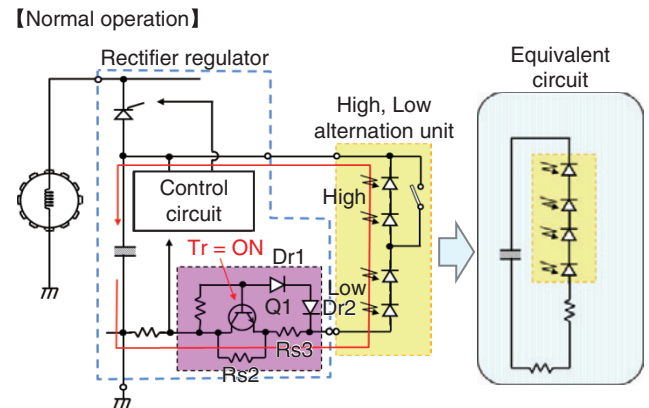


Fig. 16 Current route when normal operation

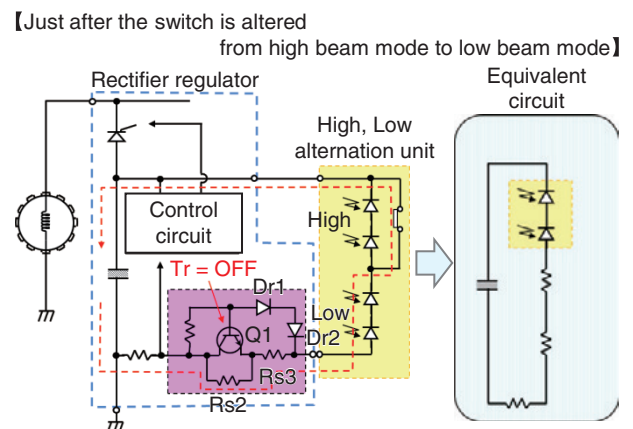


Fig. 17 Current route when rush current occurs

When the voltage of the electrolytic capacitor, CREG, decreases and current drops below 1.0 A, Q1 switches ON, and normal control is resumed.

The employment of this circuit has made it possible to control rush current, which is normally about 2.4 A, to below the rated current for the LEDs (Fig. 18).

3.3. Study of Method of Response to LED Malfunction

To ensure that the vehicle can continue to be operated even when the low beam or high beam circuit is not functioning, in normal headlights it is possible to switch, via the dimmer switch, to the beam that is functioning.

In the case of this system, when high beam is not functioning, it is possible to switch to low beam via the dimmer switch. Figure 19 shows the situation when high beam is not functioning.

However, in the present system, when low beam is not functioning, it is not possible to switch to high beam using the dimmer switch. This represented a new issue presented by this system. In response, a configuration was adopted in which a bypass circuit provided with a Zener diode and a thyristor was connected in parallel with the low beam side; when an increase in voltage between the regulator output lines is detected when low beam is not functioning, the thyristor goes into operation and power is sent to the bypass circuit, causing current to flow to the high beam

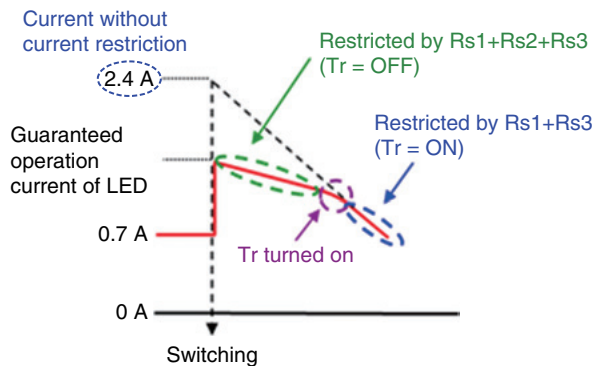


Fig. 18 Current reduction effect by rush current restriction circuit

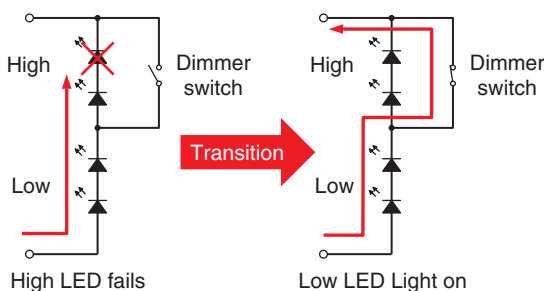


Fig. 19 Change of the current route when a LED for high beam brakes

side (Fig. 20).

The application of this measure has made it possible to employ a switch to activate high beam even when low beam is not functioning.

The development of the new technologies discussed above helped to enable the realization of activation circuits that connect high beam and low beam in series.

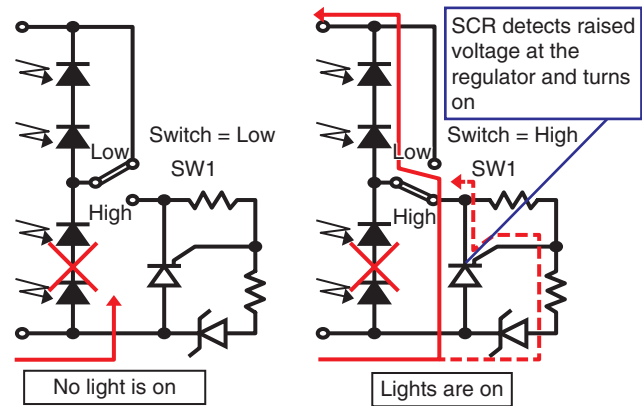


Fig. 20 Change of current route when a low beam LED brakes

4. Conclusion

LED headlights able to be employed in low-cost scooters and motorcycles have been developed. The following technologies were realized through this development.

- (1) The mounting of medium intensity LEDs on a substrate in a dispersed configuration made it possible to realize headlights that did not employ heat sinks.
- (2) The use of ACG half-wave voltage as the drive voltage for the LEDs made it possible to connect four or more LEDs in series without the use of a booster circuit.
- (3) The connection of LEDs by capacitors of appropriate capacitance made it possible to reduce the flickering resulting from ACG half-wave voltage to an equivalent level to that displayed by incandescent bulb headlights or below.
- (4) The use of a bypass circuit connected in parallel to the high beam LEDs and the control of the transmission of power to the bypass circuit via the dimmer switch made it possible to switch between high and low beams.
- (5) The use of a current reduction circuit connected in series with the LEDs made it possible to reduce the rush current generated when high beam is switched to low beam to within the acceptable current range for the LEDs.
- (6) A malfunction detection circuit, connected in parallel to the low beam circuit, has been employed as a response to malfunctions on the low beam side; this made it

possible to switch manually to high beam when LED circuits malfunction on the low beam side.

The application of these technologies has controlled the cost of LED headlights to 1.2 times that of conventional incandescent bulb headlight system. This development has made it possible to employ LED headlights in commuter scooters and motorcycles for developing countries, and can be expected to contribute to the reduction of total CO₂ emissions from motorcycles and scooters in the future.

Reference

- (1) http://www.meti.go.jp/committee/summary/0004310/pdf/018_04_00.pdf

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