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110V/220V Auto-selection Method for an LED Bulb on Shipboard

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Abstract

The strategies of low carbon and green growth have been proposed around the world for the purpose of energy conservation and environment protection. As the latest generation of light source, the light emitting diode (LED) is energy efficient and environmental friendly, which has been widely applied in the lighting industry. Traditionally, the incandescent lamp was the main light source of bulb used on shipboard. However, it has low efficiency and short lifetime. Therefore, an LED bulb that can automatically select the mains voltage on shipboard with rated voltage of 110V or 220V was proposed in this paper. The bulb consisted of 8 LED packages and a driver circuit that was mainly composed of voltage detector and analog switches. From the performance evaluation, the efficacy of the proposed bulb was about 7 times of that of the incandescent bulb. The correlated color temperature and color rendering index were 3060 K and 83, respectively. The durability test revealed that the bulb had a lifetime of 50,000 hours and can withstand the impact on shipboard. The tests of electromagnetic interference emission and susceptibility were conducted according to MIL-STD-416F, all of the specified requirements for equipment installed on surface ships were met.

Keywords: Light emitting diode, Bulb, Automatic selection method, Efficacy, Electromagnetic interference

INTRODUCTION

Compared with the conventional light sources such as the incandescent and fluorescent lamp, the light emitting diode (LED) has achieved significant share in the lighting market due to its various advantages. To be specific, the LED has high energy efficiency. Around 80% of the electricity is converted to light for LED whereas traditional light sources operate with only 20% energy efficiency and other 80% is wasted as heat. As a result, the production and import of incandescent lamp were prohibited since 2014 [1-3]. It was reported that LED lighting would achieve a market share of 68% in 2020 and over 90% in 2030. Consequently, the energy consumption would be reduced by 15% and 40%, respectively [4]. Further, the lifetime of LED is 50,000h, which is about 50 times of that of the incandescent lamp and is about 10 times of that of the fluorescent lamp. In addition, the LED has features of high durability, compact size, instant switching, and eco-friendly [5].

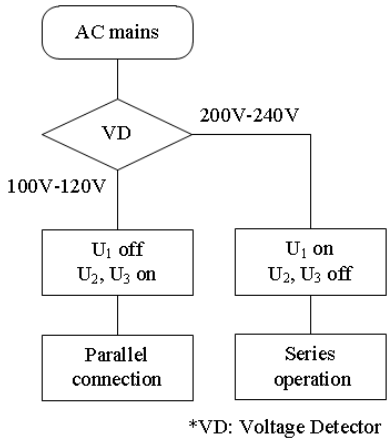
Owing to the problems including electromagnetic interference (EMI), impact, and vibration, the LED bulbs used on land cannot be implemented on the shipboard directly. Therefore, this paper discussed the development of an LED bulb for shipboard which can automatically select the mains voltage. And its electro-optical, durability, EMI, and temperature characteristics were evaluated.

DEVELOPMENT OF AN LED BULB

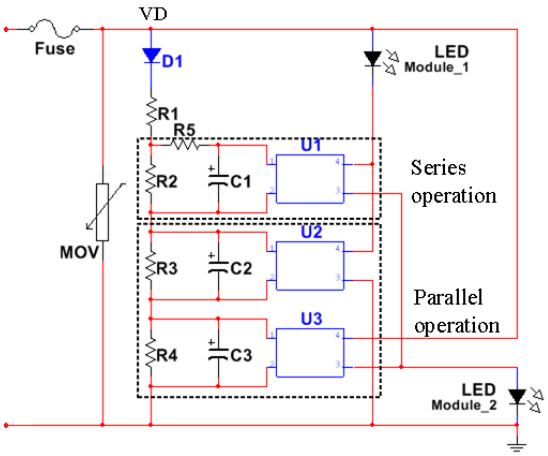
A. 110V/220V auto-selection method

The LED luminaires are usually driven by switched mode power supply (SMPS). However, the lifetime of electronic components such as the electrolytic capacitor is thermal dependent, shortening the service life of SMPS. In addition, the EMI generated from the switching action affects the function of SMPS itself and other nearby electronic equipment [6, 7]. In this paper, a driver circuit with automatic voltage selection function was designed using analog switches to avoid the EMI and to retain its lifetime expectancy.

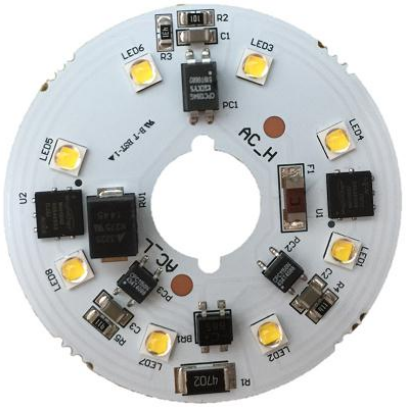
Figure 1 shows the flowchart, circuit diagram, and circuit board of the 110V/220V auto-selection method. In Fig. 1(a), the AC mains voltage is rectified by a bridge circuit. The voltage detector measures the input voltage and determines the operation mode of the LED modules. The detail principle is demonstrated in Fig. 1(b). U_1 is an A-form analog switch, and U_2 and U_3 are B-form analog switches. Taken the voltage variation into consideration, a tolerance of ±10% is used. In case of 100V-120V, U_2 and U_3 are turned on whereas the U_1 was turned off; two LED modules operate in parallel. On the other hand, LED modules work in series at 200V-240V by turning off U_2 and U_3, and turn on U_1. In addition, a metal oxide varistor (MOV) is connected in parallel with the driver circuit to protect the circuit from overvoltage. Fig. 1(c) shows the compact circuit board that consists of the driver circuit and two LED modules, each of which is composed of 4 series-connected LED package.



(a) Flowchart



(b) Circuit diagram



(c) Circuit board

Figure 1: 110V/220V automatic selection method

B. LED package

Table 1 shows the specification of LED package, including the forward current (I_f), forward voltage (V_f), luminous flux, correlated color temperature (CCT), color rendering index (CRI), and full width half maximum (FWHM). It is a surface-mount package. 4 packages constitute a LED module and 2 modules are used. These packages are well-arranged to ensure the uniform luminous distribution.

Table 1. Specification of LED package

I_f [mA]	V_f [V]	Luminous flux [lm]	CCT [K]	CRI	FWHM [°]
20	64	170	3000	80	120

C. Prototype

In addition to the circuit board, a diffuser, heat sink, housing, and E26 base are used. The diffuser is made of polycarbonate material with a transmissivity of 94%. It is used to protect the circuit board from the impact and vibration on shipboard and to avoid the glare phenomenon due to the high luminance. The aluminum heat sink is used to retain the luminous flux and lifetime of LED package since they decrease with the increasing of temperature. The prototype of LED bulb is shown in Fig. 2. It has a width of 70mm and a height of 135mm.

Figure 2: Prototype of an LED bulb

PERFORMANCE EVALUATION

A. Electro-optical characteristics

Figure 3 shows the measurement system of electrical-optical characteristics. It consisted of power supply, PC, control board, and integrating sphere. The bulb was placed inside the integrating sphere and the test was continued until the luminous flux reached to a constant value. The electro-optical characteristics of the fabricated bulb with comparison with that of an incandescent bulb are shown in Table 2. In the Chromaticity diagram as shown in Fig. 4, the coordinates of this bulb is x=0.4294, y=0.3986.

In [10], it is specified that an LED bulb with rated power consumption lower than 12W and higher than 5W should have a power factor higher than 0.9, a minimum luminous flux of 750lm, a CCT between 2,700 and 3,100, and a CRI more than 70. In Table 2, all of the requirements were met and the same characteristics were acquired at 110V and 220V. The luminous flux of a 60W incandescent bulb is 630lm whereas the luminous flux of the fabricated 12W LED is 882lm. Compared with the incandescent bulb, the LED bulb outputs 1.4 times luminous flux with only 20% power consumption. The efficacy of the proposed bulb is near 7 times of that of the incandescent bulb.

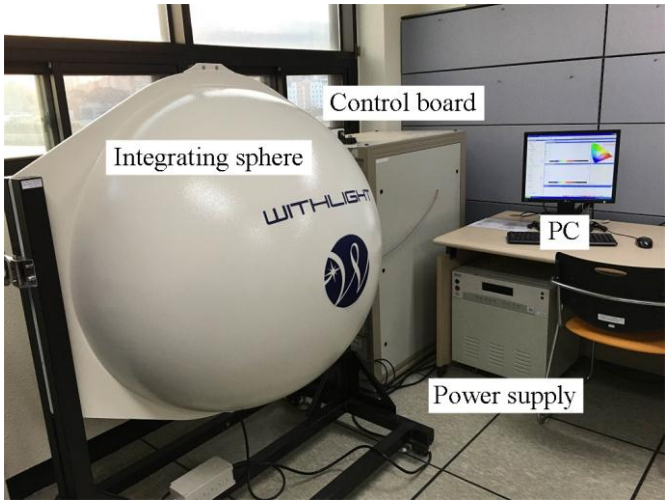


Figure 3: Measurement system

Table 2. Electro-optical characteristics

Bulb type	LED		Incandescent
Mains voltage [V]	110	220	220
Power consumption [W]	13	12	60
Power factor	0.99	0.99	1
Luminous flux [lm]	890	882	630
Efficacy [lm/W]	68	73	10.5
CCT [K]	3065	3060	2800
CRI	83	83	100

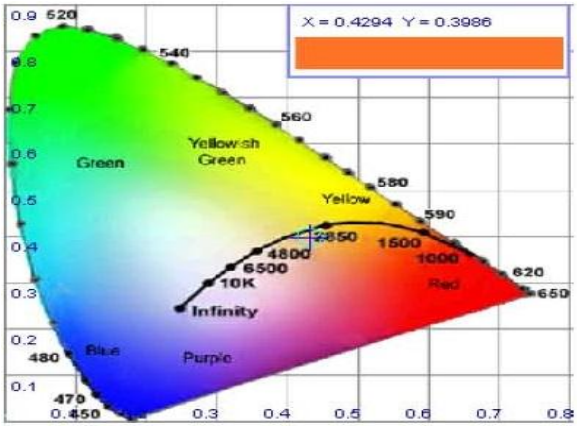


Figure 4: Chromaticity diagram

B. Durability

The durability test included the evaluation of lifetime and thermal shock.

The lifetime is defined as double of the switching times when a bulb was turned on for 30 seconds and turned off for 30 seconds under rated voltage continuously. The on/off lifetime of an LED bulb should be more than 15,000 times [8].

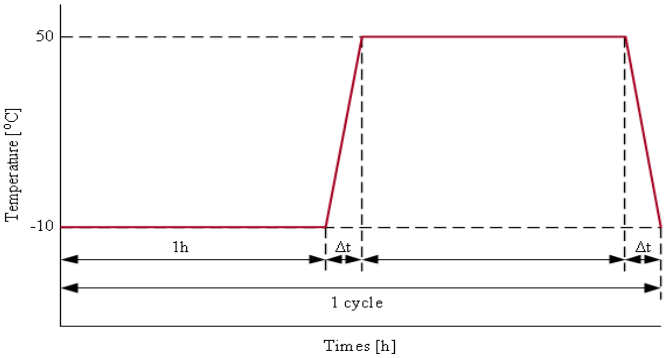


Figure 5: Temperature curve of thermal shock test

Experiment was conducted using an accelerated life tester. After switching for 25,000 times, the bulb operated normally and 99% of the initial light output was maintained. It was also verified that the lifetime of the bulb was more than 50,000h.

Figure 5 illustrates the temperature cure of thermal shock test. The bulb was placed in a test chamber at -10ºC for 1 hour and then at 50ºC for 1 hour. The time interval (Δt) was less than 5 minutes. Such procedure was repeated for 5 cycles and results indicated that the bulb operated normally.

C. EMI

The MIL-STD-416F specifies the emission and susceptibility requirements of EMI for different types of equipment and subsystems [9]. The requirements for equipment installed on

surface ships are listed in Table 3. One of the major advantages of the proposed LED bulb was its reduction in EMI. Items in Table 3 were tested by Korea Marine Equipment Research Institute. From the report, all requirements were met. Figs. 6 and 7 demonstrate the conducted emission from power leads in 30Hz-10kHz and the radiated emission of electric field from 10kHz to18GHz, respectively, where the upper line is the specified limit for surface ship application and the lower one is test result. It was illustrated that the requirements of CE101 and RE102 were not be radiated in excess of the specified requirement.

Table 3. Emission and susceptibility requirements of EMI for equipment installed on surface ships

Requirement	Description
CE101	Conducted Emissions, Power Leads, 30Hz to10kHz
CE102	Conducted Emissions, Power Leads, 10kHz to 10MHz
CS101	Conducted Susceptibility, Power Leads, 30Hz to 150kHz
CS106	Conducted Susceptibility, Transients, Power Leads
CS114	Conducted Susceptibility, Bulk Cable Injection, 10kHz to 200MHz
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads, 10kHz to 100MHz
RE101	Radiated Emissions, Magnetic Field, 30Hz to 100kHz
RE102	Radiated Emissions, Electric Field, 10kHz to 18GHz

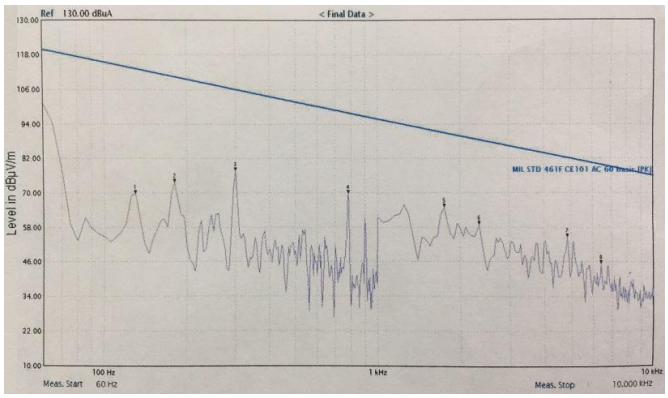


Figure 6: Conducted emission, power leads, 30Hz to 10kHz

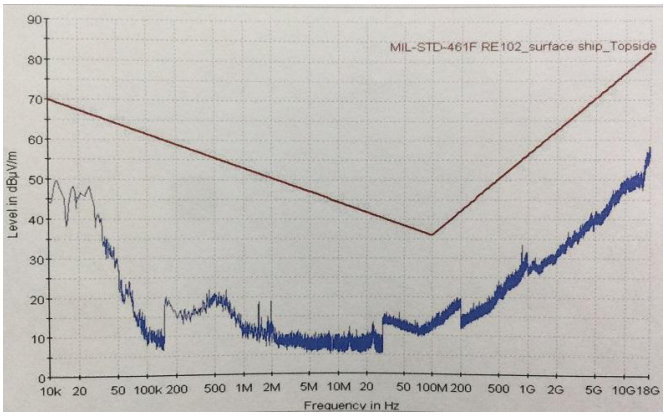


Figure 7: Radiated emission of electric field from 10kHz to 18GHz

D. Temperature

Since the luminous flux and lifetime of LED decrease with the increasing of temperature, the performance of heat radiation of the bulb is important. According to [10], the junction temperature of LED must be kept below 85 ºC in order to maintain its light output. The maximum temperature of heat sink and all the electronic components of driver must be below 70 ºC and 85 ºC, respectively. The temperatures of these parts of the bulb were measured using a thermal data logger during 2 hours at ambient temperature. Fig. 8 shows the result of thermal test. After 30 minutes, the temperature of each part reached at a constant value. It shows that temperatures of heat sink, LED module and driving component did not exceed 62ºC and 44ºC, respectively, all of which met the specified values. Fig. 9 show the thermal image of heat sink and circuit board taken by a thermal imaging camera.

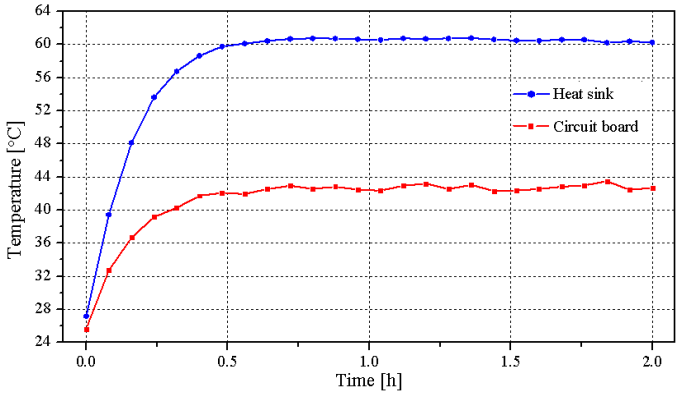
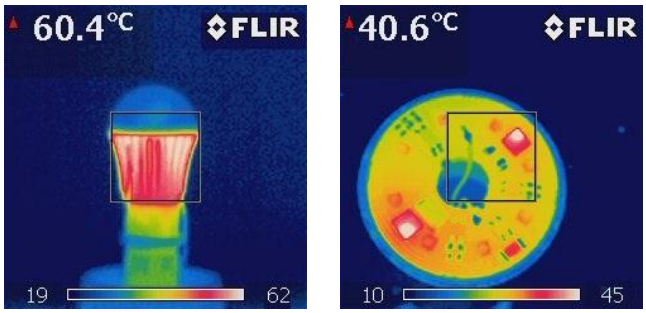


Figure 8: Result of thermal test



(a) Heat sink (b) Circuit board

Figure 9: Thermal image

CONCLUSIONS

This paper proposed an 110V/220V auto-selection method for an LED bulb used on shipboard. The controlling circuit was composed of an A-form analog switch and two B-form analog switches, whose operation modes were determined by the voltage detection circuit. The two LED modules operated in series or parallel depending on the mains voltage. From the results, the proposed bulb had an efficacy about 70lm/W, which is 7 times of that of the incandescent bulb. Its lifetime is as much as 50,000 hours and is 50 times of that of the incandescent bulb. In addition, the electromagnetic interference emission and susceptibility met the requirements specified in MIL-STD-416F.

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