Define PWM duty cycle to stabilize light emission

Application note

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Automotive Power

Never stop thinking

1 Abstract

Note: The following information is given as a hint for the implementation of the device only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.

This application note intends to provide information about duty cycle determination, necessary to drive lamps in PWM, function of the measured battery voltage.

2 Introduction

.The purpose of the PWM is to maintain the light emited by the lamp constant, regardless of the battery voltage applied. Maintaining a constant light has for consequence to maintain the electrical power constant.

2.1 Normalization of the wattage

Every bulb used in automotive applications is standardized based on its wattage. The wattage is defined at a predetermined voltage and has a given power accuracy. **Table 1** sums up the commonly used lamps in the automotive environment. Each lamp is defined as a certain voltage and the lamp's accuracy is also function of the wattage.

Table 1 Electrical parameter of the automotive bulb lamp

Official power of the lamp in W	Power accuracy in %	Voltage definition in V_{REF}
5	10	13.5
7	10	12.8
10	10	13.5
15	10	13.5
21	6	12
27	6	12.8
55	6	13.2
65	6	13.2

2.2 ILamp behavior in DC operation

The current flowing through a lamp is not proportional to the battery voltage and thus cannot be approximated by Ohm's law. **Equation (1)** is a better description of the non-linearity of the lamp current, taking into account the battery and reference voltages. The equation is derived from observed measurements. **Figure 1** sketches the 27W bulb current.

$$I_{lamp} = \sqrt{\frac{Vbat}{V_{REF}}} \times \frac{P_{lamp}}{V_{REF}} \quad (1)$$

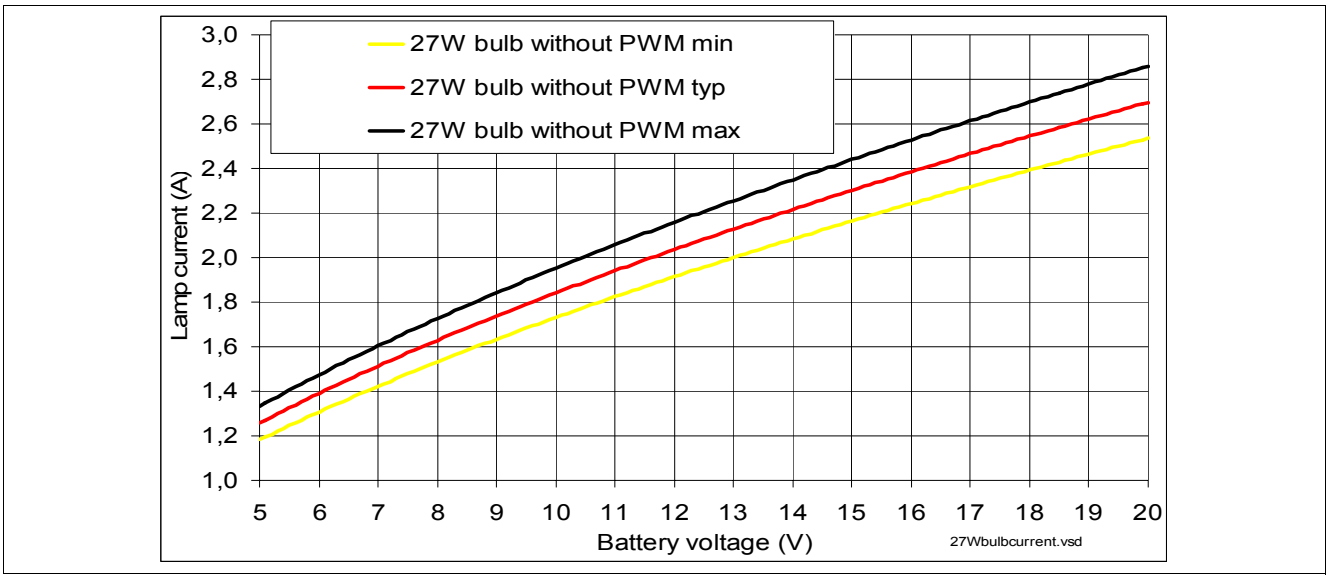

Figure 1 27W bulb current

2.3 PWM influence on the lamp behavior

The lamp resistance is linked to the filament temperature. That's the reason why the current in the lamp is root means squared dependant of the battery voltage during DC operation. As soon as the lamp is in PWM, and with the purpose to maintain the electrical power constant, the resistance is not influenced by the battery voltage and it's frozen to the voltage where the PWM starts.

2.4 Electrical parameters at the starting PWM voltage

If we call V_{PWM} the voltage where PWM starts to operate, the current I_{PWM}, value of the current in the lamp at this V_{PWM} voltage is getting easy to determine.

$$I_{PWM} = \sqrt{\frac{V_{PWM}}{V_{REF}}} \times \frac{P_{lamp}}{V_{REF}} \quad (2)$$

Let's call K, the parameter

$$K = \sqrt{\frac{1}{V_{REF}}} \times \frac{P_{lamp}}{V_{REF}}$$

K is only lamp's type dependant.

Simplified like this, **Equation (2)** looks as follow :

$$I_{PWM} = K \times \sqrt{V_{PWM}} \quad (3)$$

The lamp resistance is then **Equation (4)**:

$$R_{PWM} = \frac{\sqrt{V_{PWM}}}{K} \quad (4)$$

And last but not least, the power in the lamp at the starting PWM voltage V_{PWM} is **Equation (5)**:

$$P_{PWM} = \frac{V_{PWM}^{2}}{R_{PWM}} = K \times \frac{V_{PWM}^{2}}{\sqrt{V_{PWM}}} \quad (5)$$

3 Power in the lamp during PWM

3.1 Power in the lamp when the V_{BAT} above the PWM starting voltage V_{PWM}

To compute the average power in the lamp during PWM, the idea is to compute the energy during one PWM cycle and multiplied by the frequency F at which the PWM operates. Please refer to **Figure 2** for details.

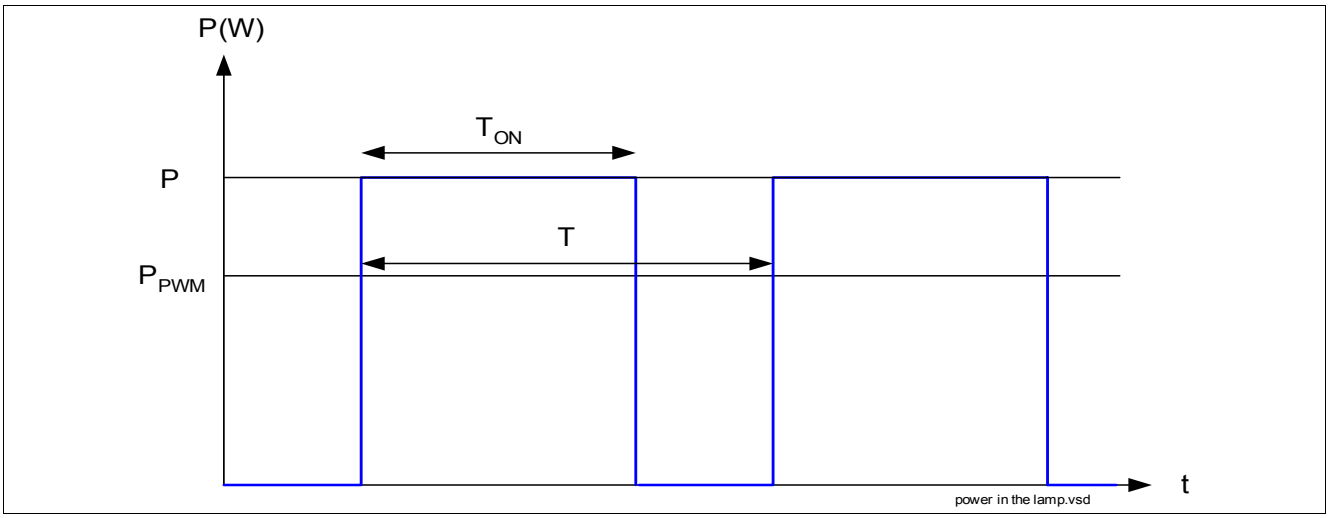

Figure 2 PWM energy, function of time.

The energy during the ON time is equaled to the surface of the square.

$$E = P \times T_{ON} \quad (6)$$

From **Equation (6)** and **Equation (4)**, the energy in the lamp is then :

$$E = \frac{V_{BAT}^{2}}{R_{PWM}} \times T_{ON} \quad (7)$$

And thus the average power in the lamp is then, with d = T_{ON} / T, definition of duty cycle.

$$P = \frac{V_{BAT}^{2}}{\sqrt{V_{PWM}}} \times d \times K \quad (8)$$

3.2 Duty cycle deduction

As said before, the target is to have P = P_{PWM}.

The quantity of **Equation (8)** and **Equation (5)** has to be equaled. It results :

$$P = \frac{V_{BAT}^{2}}{\sqrt{V_{PWM}}} \times d \times K = \frac{V_{PWM}^{2}}{\sqrt{V_{PWM}}} \times K$$

Symplifying both quantities, it results the duty cycle is defined by :

$$d = \frac{V_{PWM}^{2}}{V_{BAT}^{2}}$$

3.3 Conclusion

To perform PWM on lamps, with the goal to maintain a constant light emission, the duty cycle is independant of the lamp wattage, independant of the PWM frequency, and depends only on the square of the battery voltage.

4 Dimming a lamp to substitute lower wattage

It is sometimes requested to dim a defined wattage to substitute lower wattage. For example, to dim the 27W break light to replace a broken 5W park light. The following chapter will defined the way to proceed.

Let's call L_{break} the lamp we want to simulate, and L_{dim}, the lamp we're using as spare. Same convention will be used for all others parameter such as K_{break} is the K factor of the broken lamp.

In **Chapter 2.4**, we have defined the a factor, called K, which is lamp specific. A very simplistic way to proceed would be to say that d, the duty cycle we are looking for is **Equation (9)**.

$$d_{dim} = \frac{K_{break}}{K_{dim}} \tag{9}$$

With such a formula, the defined duty cycle will be as sumed up in **Table 2**:

Please note dimming of a lamp can only reduce the power and obviously not increasing it so performing PWM to dim a 5W bulb to generate a 27W is non sense

.

Table 2 Duty cycle definition for dimming in percent

	Broken lamp L_{break}						
Lamp to dim L_{dim}	**5**	**7**	**10**	**15**	**21**	**27**	**55**
7	66	100					
10	50	76	100				
15	33	51	67	100			
21	20	30	40	60	100		
27	17	26	34	51	86	100	
55	9	13	18	26	44	51	100
65	7	11	15	22	37	44	85

By using such a fixed duty cycle, the effect is the light emission is no more stabilized, in regards to battery voltage. this is usually sufficient, assuming that we're already in a faded mode.

5 Revision History

Define PWM duty cycle to stabilize light emission

Revision History: Rev 0.2, 2007-11-16

Previous Version(s):
Rev. 0.0, 2007-09-20

Page	Subjects (major changes since last revision)
2	Modification of the Abstract text

Edition 2007-11-16

Published by
Infineon Technologies AG
81726 Munich, Germany

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