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MODELING AN OPTOELECTRONIC SYSTEM WHICH INCLUDES ONE LED AND ONE PHOTODIODE

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Abstract: In this study, the model relations of an optoelectronic system which include a LED and a photodiode which are connected with the information of light have been obtained. The voltage which measured from the anode of photodiode is used as proportional value with radiant power of LED. Because of using this value as model parameter instead of radiant power, all the magnitudes that used in the model relations are electrical magnitudes. The system equation can be expended by adding the information of optical medium that the light has been passed through, if it necessary.

Keywords: LED, modeling, photodiode.

Bir LED ve Bir Fotodiyot İçeren Optoelektronik Sistemin Modellenmesi

Özet: Bu çalışmada, ışık bilgisiyle bağlı bir LED ve bir fotodiyot içeren bir optoelektronik sistemin model bağıntıları elde edilmiş bulunmaktadır. Fotodiyodun anodundan ölçülen gerilim, LED'in ışık şiddetiyle orantılı bir değer olarak kullanılmaktadır. Işık şiddeti yerine model parametresi olarak bu değerin kullanılması nedeniyle, model bağıntısında yer alan bütün büyüklükler elektriksel büyüklüklerdir. Eğer gerekli görülürse, ışığın içinden geçtiği optik ortamın bilgisi de eklenerek sistem eşitliği genişletilebilir.

Anahtar Kelimeler: LED, modelleme, fotodiyot.

1. INTRODUCTION

To obtain the model relations of whole optoelectronic system is very important in some applications for example in optical sensor system modelling, LED-photo diode system modelling for electronic circuit simulation program. Let consider one LED and one photodiode which are located on the same line and photo diode is biased such that it has been formed a photo detector which works in photoconductive mode. Such an optoelectronic system has been shown in Figure 1 (Ozuturk, 2013), (Ozuturk, 2000). Using a pulse oscillator which is formed by a 555 timer, the current pulses have been passed through the LED. The duty cycle / period ratio is so less that current pulses can be assumed as single pulse (not periodically). The amplitude of current pulses and pulse duration can be changed. For measuring LED's radiant power a basic photo detector is used. The photo detector formed by connecting a resistor and a photodiode as photoconductive mode. The measured voltage on the resistor is proportional with radiant power incident on the photodiode. Using the circuit which given in Figure 1 the graphic which given in Figure 2 has been obtained by measuring photo detector voltages and LED currents for different pulse

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durations (Ozuturk, 2013), (Ozuturk, 2000). Figure 2 has been modelling the optoelectronic system examined here graphically for a specific distance between LED and photodiode.

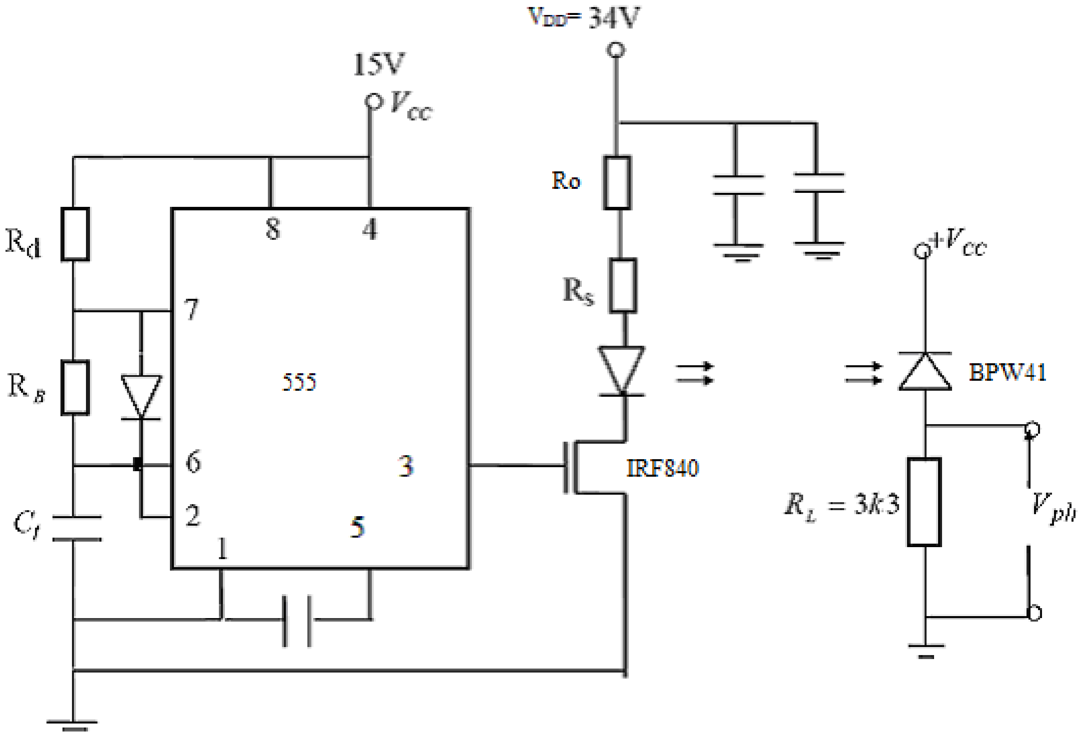

Figure 1:
An oscillator formed by 555 timer for produce current pulses for LED and a photo detector circuit formed by BPW41 photodiode connected in photoconductive mode (Ozuturk, 2013), (Ozuturk, 2000).

2. DERIVING OF THE MODEL RELATION

If the distance between LED and photodiode is L, measured photo detector voltage which is proportional to LED's radiant power for this distance becomes as $P(L) = F_0 / L^2$. Here, F_0 is a constant which is depend on medium between LED and photodiode and it is equal to $F_0 = P(L) \times L^2$. The coefficient F_0 can be calculated using a measured value of photo detector voltage measured for a suitable distance L (the distance L should be long enough to avoid saturation of photodiode). Once F_0 is calculated, the equation between photo detector voltage and any distance x can be written as $P(x) = F_0 / x^2$.

According to the (Ozuturk, 2013) the following equation can be written:

$$P(L) = P_n(t, I_n, V_n) = k_{pn} I_n (1 - K(t) a V_n I_n) \quad (1)$$

This equation has been obtained in pulsed high current operation. In this equation L is the distance between LED and photodiode. t is the pulse duration of photo detector voltage (photo detector voltage has been measured after t time from the beginning of the current pulse of LED). I_n is the amplitude of LED’s current pulse. V_n is the voltage drop on the LED. k_{pn} is the electrooptic converter between current and photo detector voltage at low LED currents where the thermal effect of LED can be neglected and LED's radiant power varies almost linearly with LED current. *K(t)* is the product of thermal impedance of LED and *k* (*k.Z(t))* and it can be calculated using some suitable measured values (Ozuturk, 2013). The thermal impedance is $Z(t) = (T_j(t) - T_a) / P_d(t)$ where $T_j(t)$ is the junction temperature, T_a is the ambient temperature and $P_d(t)$ is the thermal power dissipated in junction. *k* is a constant and it used to determine the linear junction temperature-radiant power characteristic of LED. Sometimes it is specified as a constant like *k* = 0.7% / ˚C. A production can be defined as $k_{pn} I_n k = \Delta P / \Delta T_j$ where ΔP is equal to the difference of radiant power for the change in junction temperature as $\Delta T_j = (T_j(t) - T_a)$ and $k_{pn} I_n$ is the radiant power before junction has not heated as ΔT_j. The electrical power applied to the junction is $V_n I_n$. The total radiant efficiency of LEDs which are used for general purposes is between 1% and 5% and rest of the applied electrical power turns to thermal power. $aV_n I_n$ is the thermal power ($P_d(t)$) and *a* is a constant ($a = (0.975 \pm 0.025)$). So $k_{pn} I_n K(t) a V_n I_n$ has been equal to ΔP.

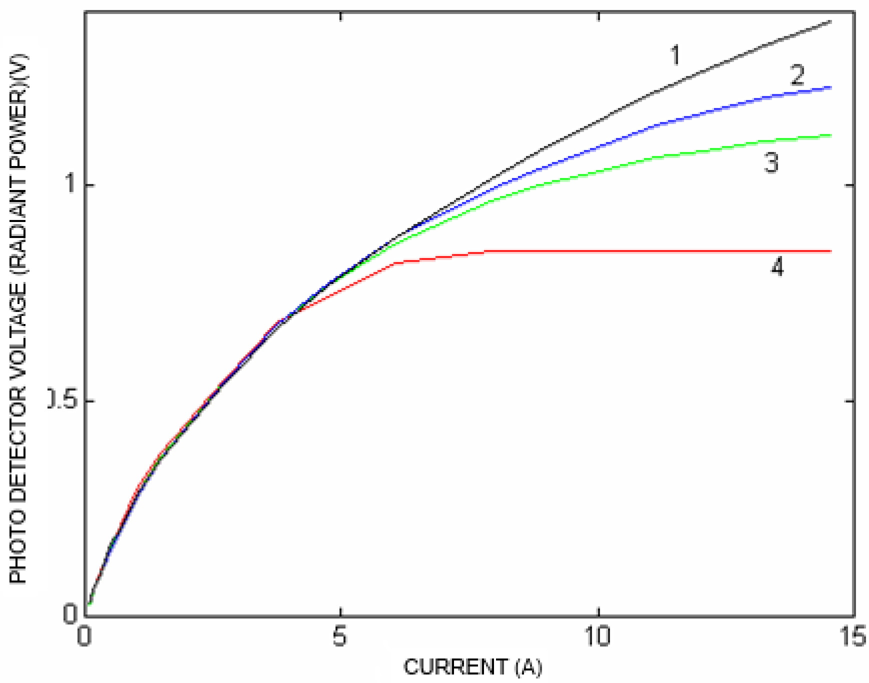

Figure 2:
Current-radiant power characteristics of LED (SLR 932 A (Sanyo)). Pulse duration for each curve are 1-3.5 μ s, 2-6.5 μ s, 3-9 μ s, 4-18 μ s respectively.

Using equation (1) the following equation can be written:

$$P_n(t, I_n, V_n, x) = \frac{F_0}{x^2} = \frac{L^2(k_{pn} I_n (1 - K(t) a V_n I_n))}{x^2} \quad (2)$$

Last equation gives photo detector voltage for any distance x.

After a limit current value (after then 4A-5A) the instantaneous resistance (V_n / I_n) of LED became approximately constant (which this constant value is equal to the sum of contact and bulk resistances of LED) (Ozuturk, 2013), (Ozuturk, 2000), (Ozuturk, 2002). If this constant resistance shown as r_b the equation (2) can be written as follows:

$$P_n(t, I_n, x) = \frac{L^2 (k_{pn} I_n (1 - K(t) a r_b I_n^{\ 2}))}{x^2} \tag{3}$$

Photo detector voltage depends on the medium between LED and photodiode. If the medium conditions are changed at any time this effect can be added to the equation by production the last equation with a constant, for example k_a.

In above explanation it is assumed that LED and photodiode are located on the same axes. If LED angle is changed the photo detector voltage will be changed. New photo detector voltage can be found by production the equation (3) with a number (k_θ) which varies with angle (Ozuturk, 2002).

There is an event which has not been included in equation (3). LED spectral characteristic has been shifted because of heating. At worst case, approximately 5% attenuation has been occurred at radiant power of GaAs LED for this shifted wavelength because of spectral response of BPW41 photodiode (Bradbury, 1991), (Ozuturk, 2006), (Ozuturk, 2013), (Ozuturk, 2000). It must be known that equation (3) must include a multiplier in this situation. If approximately value of it can be known, a multiplier (k_λ) should be used in equation (3) for this effect.

Photo detector voltage is the product of photodiode photo current with equivalent resistor which could be found from the anode of photodiode. The equivalent resistor of photo detector can be at different values. The reverse biased photodiode has very big internal resistor. Equivalent external resistor of photo detector has been chosen low enough than internal resistor of photodiode. If the external equivalent resistor value is R_m for a measured photo detector voltage, the photo current can be found by production of photo detector voltage by $k_i = 1 / R_m$. To find photo detector voltage for any other values of photo detector external resistors (R_{pd}), equation (3) must be produced by $k_i R_{pd}$.

Sometimes, some optoelectronic components like lenses or reflectors can be used in the medium of optoelectronic system. In this situation the photo detector voltage can be changed according to free space transmission of light depending on the transparency coefficient of lenses or reflection coefficient of reflectors. In this situation a coefficient like k_{oc} must yield in equation (3) (Wilson and Hawkes, 2000), (Ozuturk, 2006).

The following equation which includes all effects mentioned above can be written as follows:

$$P_n(t, I_n, V_n, x) = \frac{k_{oc} k_i R_{pd} k_\lambda k_\theta k_a L^2 (k_{pn} I_n (1 - K(t) a V_n I_n))}{x^2} \tag{4}$$

3. CONCLUSION

Equation (4) gives photo detector voltage according to LED's current pulse amplitude, current pulse duration, voltage drop on LED, distance between the LED and photo diode and some constant parameters. Equation does not include LED's optical power. So there is no need to make LED's light optical measurements. Such an equation can be used to modelling sensor systems which consist of one LED and one photo diode. The equation derived here can be also used in electronic circuit simulation programs. Available circuit simulation programs have no models and model relations to simulate optoelectronic system which includes LED and photo diode yet.

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