A DISCHARGING METHOD FOR A PREVIOUSLY CHARGED CAPACITOR THROUGH SEMICONDUCTOR LIGHT EMITTER

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ABSTRACT

Analysing the driving methods of semiconductors, one can determine the methods of direct connection to the supply, driving with a coil and discharging the previously charged capacitor through the semiconductor light emitter (driving with a storage capacitor). The method of direct connection to the supply is used at small currents and the flowing current is limited by the internal resistance of the source in this method. The method of driving with a coil is used in cases where it is required to obtain high voltage from low voltage and low voltage from high voltage (DC/DC converter). In the method of driving with a storage capacitor, the internal resistance of the supply is made ineffective and so break down of the semiconductor light emitter at large pulse currents is prevented.

Equations required for selecting optimal values of circuit elements values in the method of driving with a storage capacitor has been obtained. A double capacitor circuit has been proposed to increase the operating frequency.

I. INTRODUCTION

Some driving methods of semiconductor light emitters (UVLED, LED, IR emitter, semiconductor laser) are direct connection to the supply [1-5,7], driving with a coil [9-13] and discharging the previously charged capacitor through the semiconductor light emitter [15-18].

In direct connection method, current flowing through the semiconductor light emitter is limited by internal resistance of the source. This method is used at small currents [8, 14].

Driving with a coil is used to connect semiconductor light emitters with high threshold voltages to low voltage supplies or to obtain low voltage from high voltage [11, 13, 19], e.g. LEDs connecting in series to a 1.5 V battery.

II. CHARGING AND DISCHARGING PROCESSES OF THE CAPACITOR

To analyse the method of discharging the previously charged capacitor through the semiconductor light emitter, let us consider charging and discharging processes of the capacitor. The circuit and time diagrams describing these processes are shown in Figure 1.

To obtain large currents in these types of circuits, high voltages, i.e. hundreds of volts, are used and therefore LED threshold voltage can be ignored since $U_{CC} >> U_{LED}$.

Let us examine the circuit shown in Figure 1. Initially, SW1 is closed and SW2 is open. The capacitor starts to charge via the resistor R. The voltage on the capacitor begins to increase in the form

$$U_C = U_m\left(1-\exp\left(-\frac{t}{RC}\right)\right) = U_m\left(1-\exp\left(-\frac{t}{\tau_1}\right)\right) \quad (1)$$

where $\tau_1=RC$ is the time costant of the charging circuit.

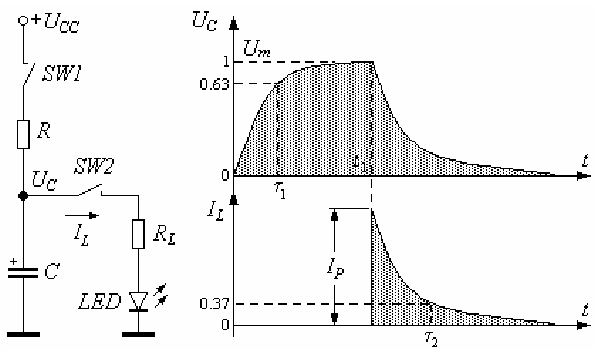

Figure 1. Simplified scheme of the method of discharging the previously charged capacitor through the semiconductor light emitter and related time diagrams

Charging time of the capacitor t_f can be described as

$$t_f=3\tau_1=3RC \quad (2)$$

since voltage U_C is supposed to reach the supply voltage in $3\tau_1$ ($U_m=U_{CC}$). When the charging process of the capacitor is over, SW1 is opened and SW2 is closed at the time t_1 ($t_1 = t_f = 3RC$). The capacitor starts to discharge through the semiconductor light emitter at the time t_1 as shown in Figure 1. In this case, current flowing through the semiconductor light emitter varies as

$$I_L = \frac{U_C}{R_L}\exp\left(-\frac{t}{R_L C}\right) = \frac{U_{CC}}{R_L}\exp\left(-\frac{t}{R_L C}\right) \qquad (3)$$

where $R_L C = \tau_2$ is the time constant of the discharging circuit. The peak value of the current can be determined by the resistance R_L and the supply voltage U_{CC} as

$$I_p = \frac{U_C}{R_L} = \frac{U_{CC}}{R_L} \qquad (4)$$

III. REALISATION OF THE METHOD OF DISCHARGING THE PREVIOUSLY CHARGED CAPACITOR THROUGH THE LIGHT EMITTER

To realize this method, a switch and an RC circuit is required. The analysis tends to calculate the optimal RC values according to previously determined current values. Such a circuit type is shown in Figure 2, where bipolar transistor (or MOSFET instead) operates as a switch,

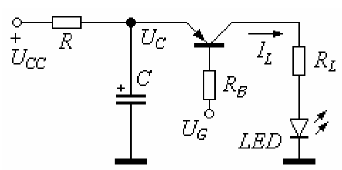

Figure 2. Switching circuit with a transistor

R is the resistor loading the capacitor, R_L is the current determining resistor, R_B is the resistor determining the transistor base current. If periodic pulses are given to the base terminal of the transistor, two cases occurs.

First case: Complete discharge of the capacitor through the semiconductor light emitter. In this case, transistor is in the saturation mode during the duration t_D, where $t_D = 3\tau_2 = 3R_L C$, i.e. the condition $t_D \geq 3R_L C$ is valid. Time diagrams describing this case are shown in Figure 3.

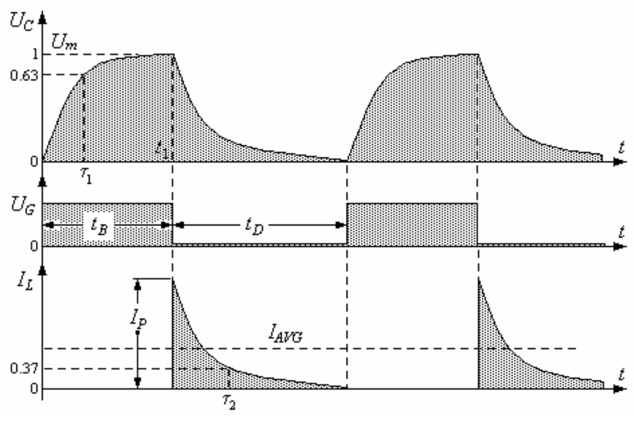

Figure 3. Time diagrams describing the case $t_D \geq 3R_L C$

When the transistor is in the saturation mode, ignoring the transistor saturation voltage and LED threshold voltage (since $U_{CE(sat)} << U_{CC}$ ve $U_{LED} << U_{CC}$), current flowing through LED can be expressed as

$$I_L = C\frac{dU_C}{dt} = -\frac{U_C}{R_L}\left[\exp\left(-\frac{t}{R_L C}\right)\right] \qquad (5)$$

If time factor of the exponential current $\tau_2 = R_L C$, discharging duration $t_D = 3R_L C$ and the duration between exponential pulses $t_B = 3RC$ are known, average value of the current flowing through LED for the case of exact exponential current flowing through LED can be computed with

$$I_{AVG} = \frac{1}{T}\int_0^T I_L\,dt = \frac{1}{t_D + t_B}\int_0^{t_D} \frac{U_{CC}}{R_L}\exp\left(-\frac{t}{R_L C}\right)dt$$

$$\approx 0{,}317 \underbrace{\frac{U_{CC}}{R_L}}_{=I_p} \frac{t_D}{t_D + t_B} = 0{,}317.I_p\frac{t_d}{T} \qquad (6)$$

For this case, i.e. exact exponential current flowing through LED, operating frequency of the circuit will be

$$f_T = \frac{1}{3C(R_L + R)} \qquad (7)$$

The bigger the value of resistor R is chosen, the bigger the internal resistance of the supply source can be. The smaller the capacitance of the capacitor is chosen, the bigger the operating frequency will be. In large currents, the value of R_L is generally very small ($R_L << R$) and therefore the value of charging resistor effects the operating frequency of the circuit, i.e. operating frequency can be written as

$$f_T \approx \frac{1}{3RC} \qquad (8)$$

Second case: The duration of the current flowing through the semiconductor light emitter is $t_D < 3R_L C$. Time diagrams describing this case are shown in Figure 4.

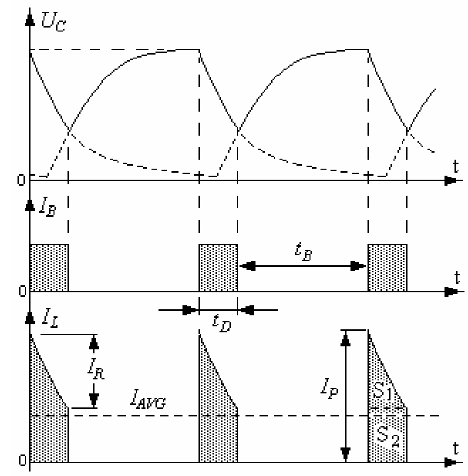

Figure 4. Time diagrams describing the case $t_D < 3R_L C$

In this case, pulse current flowing through LED has two parts: the upper part (the area S_1 in Figure 4) and the lower part (the area S_2). The smaller the upper part of the flowing pulse current will be, the fewer breakdowns in photosignal shape will occur. The upper area depends on the capacitance of the capacitor and the value of charging resistor. Let us call the ratio of these areas as "shape breakdown ratio" or shortly K_S and analyse the variation of it with R_LC.

The value of K_S can be computed with

$$K_S = \frac{S_1}{S_2} \cdot 100 = \frac{\int_0^{t_D} I_L dt - t_D \left(I_p - I_R\right)}{\int_0^{t_D} I_L dt} \cdot 100$$

$$= \left[1 - \frac{t_D \exp\left(-\frac{t_D}{R_L C}\right)}{R_L C \left(1 - \exp\left(-\frac{t_D}{R_L C}\right)\right)} \right] \cdot 100 \qquad (9)$$

Variation of K_S with $\tau_2 = R_LC$ obtained by the MATLAB program is shown graphically in Figure 5. It is obvious from these graphs that K_S can be decreased by decreasing the duration t_D and increasing the value of τ_2. When the value of storage capacitor is increased, the area S_1 decreases.

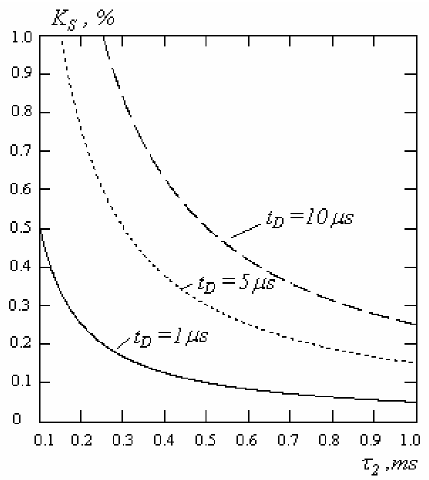

Figure 5. Variation of K_S with $\tau_2 = R_LC$ obtained by the MATLAB program

To obtain large pulse currents, R_L must be kept small. Therefore, time constant of the circuit is determined by the capacitance of the capacitor.

In the second case, the current flows only during the duration t_D. In this case, the average current flowing through the light emitter will be

$$I_{AVG} = \frac{1}{T} \int_0^{t_D} I_L dt = I_p \frac{R_L C}{t_D + t_B} \left[1 - \exp\left(-\frac{t_D}{R_L C}\right) \right] \qquad (10)$$

With the help of (10), average current can be found. Considering that average current is equal to the nominal current ($I_{AVG} = I_N$), the maximum value of the pulse current can be found as

$$I_m = I_p = I_N \frac{t_D + t_B}{R_L C} \frac{1}{\left[1 - \exp\left(-\frac{t_D}{R_L C}\right) \right]} \qquad (11)$$

From (11), the value of supply voltage U_{CC}, capacitance of the capacitor C, the value of charging resistance R and the resistor determining the current R_L can be computed for required pulse current and pulse period.

IV. CONCLUSION

The method of discharging the previously charged capacitor through the semiconductor light emitter has various advantages. These are; the internal resistance of the supply does not effect the pulse current; in the circuit containing capacitor, the current flowing through the semiconductor light emitter is determined only by the energy stored on the capacitor and this prevents the breakdown of semiconductor light emitter at large currents. Disadvantages of the method can be mentioned as; pulse is different from square pulse (breakdowns in the shape) and the operating frequency depends on the capacitance of the storage capacitor.

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