PSPICE Modeling of Commercial ICs for Switch-Mode Power Supply (SMPS) Design and Simulation

Yun Jae Yi, Yun Seop Yu, *Member, KIMICS*

***Abstract*— PSPICE modeling of a commercial LED driver IC (TOP245P) and PC817A optocoupler is proposed for the switch-mode power supply (SMPS) (applicable to LED driver) design and simulation. An analog behavioral model of the TOP245P IC including the shunt regulator, under-voltage(UV) detection, over-voltage(OV) shut-down and SR flip-flop is developed by using PSPICE. The empirical equation of PC817A current transfer ratio (CTR) is fitted from the datasheet of PC817A. Two types of SMPSs are simulated with the averaged-model and switching-model. The simulation results by the proposed PSPICE models are in good agreement with those in the data sheet and an experimental data**.

***Index Terms*— LED driver, switch-mode power supply, analog behavioral model, PSPICE, optocoupler**

I. INTRODUCTION

THE interest for using light-emitting diodes (LEDs) for lighting applications has been growing steadily over the past few years. Because the LEDs have some advantages such as higher efficiency, longer lifetime, smaller size, and environment friendly, it brings a perspective which the most illuminating equipments are replaced by the LEDs technology in the future [1,2]. Therefore, there are many types of LED drivers commercialized by industries on the market. However, the lifetime of the LED driver circuits is relatively shorter than that of LEDs. In order to enhance power efficiency of the LED driver circuit, power LEDs have to be supplied to switch-mode power-supplies (SMPSs) [3]. The LED driver ICs are very important to design the SMPSs in LED illumination systems. The driving technique used by LED driver ICs is more commonly known as the burst-mode or pulse-width modulation (PWM) driving technique. This is a method by which the LED is switched on and off at high frequency and the luminous intensity is controlled by adjusting the duty cycle, which is the ratio of the time for which the device is ON to the switching period, and hence the average forward current. Although manufacturers making commercial LED driver ICs provide datasheets, application notes, and design tools, they have generally not given SPICE models of the driver ICs which can design more efficiently various types of application circuits.

In this paper, we would propose the PSPICE modeling technique of commercial ICs for the SMPS (applicable to LED driver) design and simulation. For example, modeling of TOP245P IC [4] (made by Power Integration corp.) and PC817A optocoupler [5] (made by Sharp Electronic com.) are introduced. Simulation of SMPS including the PSPICE analog behavioral models of the TOP245P IC and PC817A optocoupler will be performed, and the simulation results will be compared with the data sheets and the experimental data to verify the accuracy of modeling.

II. MODELING

A. PC817A

Optocoupler transfers electrical signals by utilizing light waves to provide coupling with electrical isolation between its input and output. The most important parameter for most optocouplers is their transfer efficiency, usually measured in terms of their current transfer ratio (CTR), which is simply the ratio between a current change in the output transistor and the current change in the input LED.

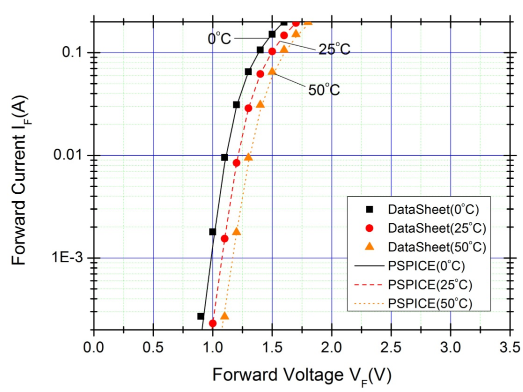

Fig. 1. Forward current-forward voltage characteristics of diode in PC817A optocoupler as a function of temperature.

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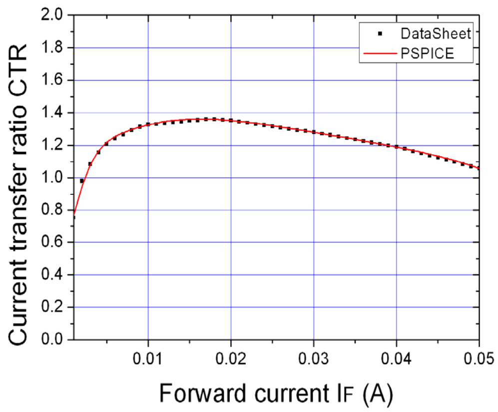

Fig. 2. Current Transfer Ratio vs. Forward Current of PC817A optocoupler.

Parameters of a diode in PSPICE are extracted from fitting the forward current-forward voltage characteristics in datasheet of PC817A, and follow as I_s = 0.82 pA, N = 2, R_s = 1.82 Ω, and C_{jo} = 1 pF. Figure 1 shows the forward current-forward voltage characteristics of a diode in PC817A optocoupler as a function of temperature (T). Symbols and lines denote data of diode in datasheet and simulation results of the diode with extracted parameters by PSPICE, respectively. Squares, circles, and triangles denote T = 0, 25, and 50 °C, respectively. The simulation results by the proposed PSPICE diode model are in good agreement with those in the data sheet.

CTR model of PC817A in PSPICE is extracted from fitting CTR data in datasheet of PC817A, and the equation of CTR follows as

$$CTR = \begin{cases} 0.52657 + 277.20608I \\ \quad - 3579600373I^2 + 1618800I^3, & \text{for } 0.001 \le I < 0.01 \\ 1.0389 + 49.7546I - 2566.55064I^2 \\ \quad + 50740.18203I^3 - 383029.4604I^4, & \text{for } 0.01 \le I \le 0.05 \end{cases} \quad (1)$$

By using the ETABLE and current-controlled current-source of analog behavioral model (ABM) in PSPICE, Eq. (1), the relation between LED and photo-transistor in optocoupler, is modeled. Figure 2 shows the CTR vs. forward current of PC817A optocoupler. Symbols and lines denote data of datasheet and simulation results by PSPICE modeling, respectively. The simulation results by the proposed PSPICE modeling are in good agreement with those in the data sheet.

B. TOP245P

Functional block diagram in TOP245P is shown in Fig. 3. TOP245P consists roughly of SHUNT REGULATOR, OSCILLATOR, SOFT START, and OV/UV. OSCILLATOR operates at a frequency of 132 KHz, and SOFT START block limits the peak current and voltage during the start-up period of 10 ms. OV/UV block protects the internal circuit of TOP245P, by detecting abnormal behaviors such as over and under normal voltage range. TOP switch series, made by Power Integration corp., control the output current by adjusting the duty cycle with a shunt regulator, and the shunt regulator adjusts the duty cycle of drain-source current in terms of input current of CONTROL pin. Therefore, modeling of the shunt regulator is required. Figure 4 shows an equivalent circuit of shunt regulator in TOP245P, using PSPICE ABM devices. Figure 5 shows the duty cycle vs. input current of CONTROL pin. As the input current of CONTROL pin increases, the duty cycle of the output current reduces and the increase of output voltage is limited. When the input current is very small, the duty cycle is limited to maximum 78 %. Symbols and lines denote data of datasheet and simulation results by PSPICE modeling, respectively. The simulation results by the proposed PSPICE modeling are in good agreement with those in the data sheet.

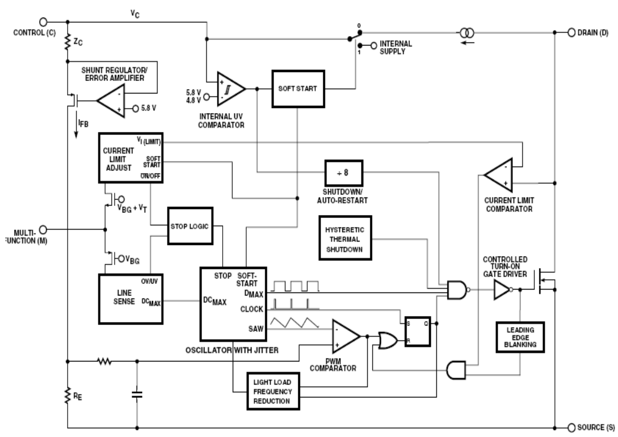

Fig. 3. Functional block diagram in TOP245P.

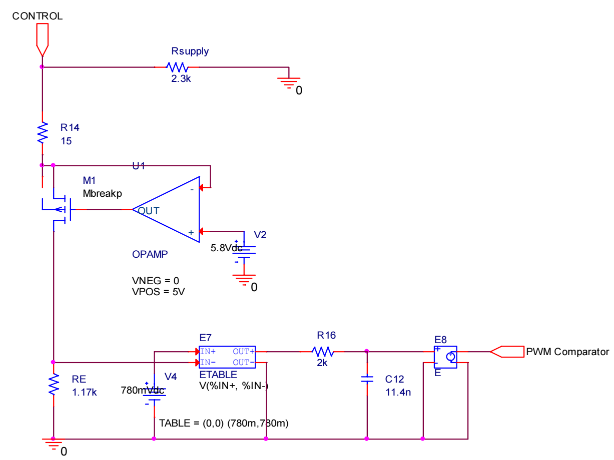

Fig. 4. Equivalent circuit of the shunt regulator in TOP245P.

TOP245P embedded the shut-down function at under-voltage and over-voltage of normal operation voltage range to protect the internal circuit. The voltage-controlled voltage-source (VCVS) in PSPICE is used for modeling the OV/UV block as shown in Fig. 6. When the voltage of below 100 V and above 450 V is detected, the shut-down signal generates to protect the internal circuit.

Output of PWM COMPARATOR is connected to Reset of SR flip-flop and CLOCK of OSCILLATOR is connected to Set of SR flip-flop. The VCVS in PSPICE is used for modeling the SR flip-flop as shown in Fig. 7.

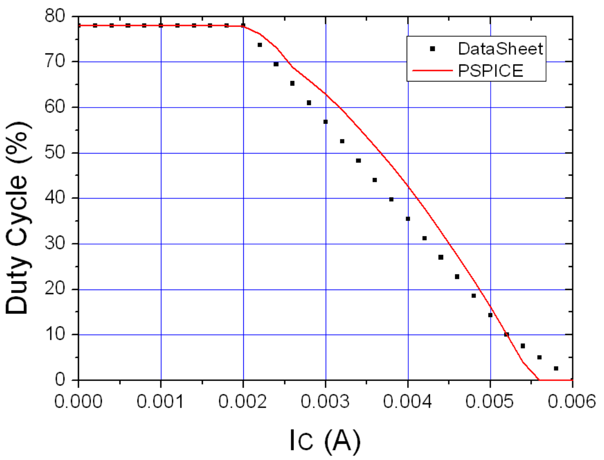

Fig. 5. Relationship of input current of CONTROL pin to the duty cycle.

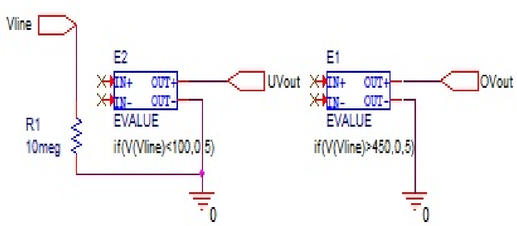

Fig. 6. Equivalent circuit of UV and OV function.

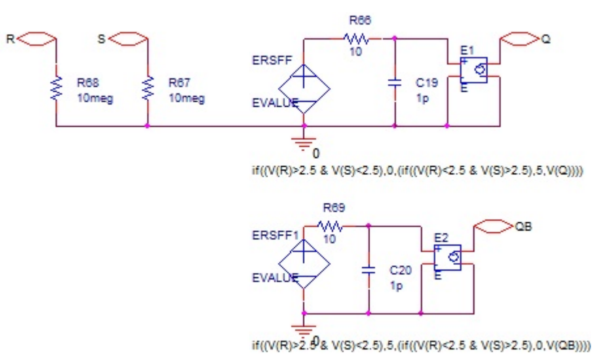

Fig. 7. Equivalent circuit of SR flip-flop.

Blocks unrelated directly to the switching function were excluded from this modeling.

III. SIMULATION AND EXPERIMENTAL RESULTS

Figure 8 shows an example of an application circuit of TOP245P for audio amplifier power supply [6]. The SMPS as shown in Fig. 8 is simulated by using modeling of PC817A and TOP245P using the PSPICE ABM devices with two types of simulation methods such as averaged model and switching model [7], and the simulation results are shown in Fig. 9. Symbols and lines denote the simulation results of averaged model and switching model, respectively. Table I shows the comparison of simulation results between averaged and switching models. The simulation results of averaged and switching models are close to the output voltage of about 16V, which shows that the accuracy of the modeling of TOP245P IC including a shunt regulator is validate.

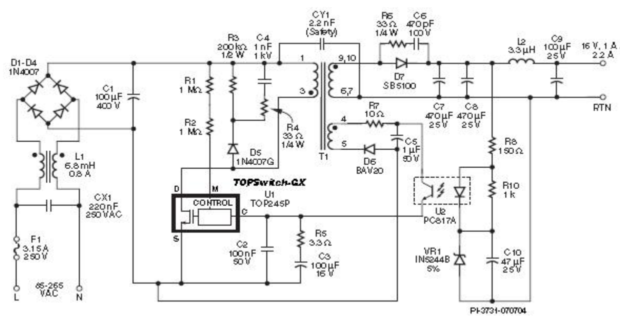

Fig. 8. An Application circuit of TOP245P for Audio amplifier power supply [6].

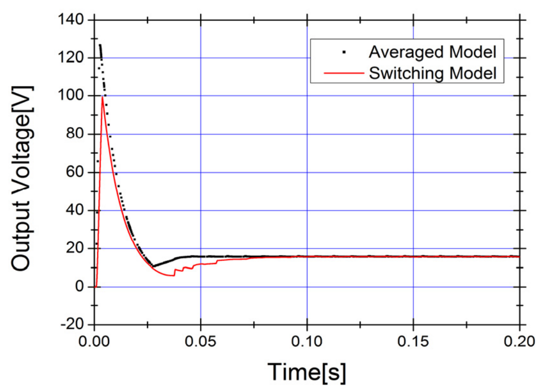

Fig. 9. Transient simulation results of the output voltage in the application circuit as shown in Fig. 8.

TABLE I
COMPARISON OF SIMULATION RESULTS BETWEEN AVERAGED AND SWITCHING MODELS (UNTIL 120 ms)

Models	Averaged model	Switching model
Simulated time	0.7 s	883.89 s
Created data	612 KB	0.98 GB

However, there are much difference of the simulation time and amount of created data between the averaged and switching models. Each method has to be chosen, depending on the purpose of circuit simulation.

Figure 10 shows the output voltage and current of the application circuit for 8W LED driver [8]. Symbols, solid lines, and dotted lies denote the experimental data, the simulation results of averaged model, and the simulation results of the switching model, respectively. The simulation results of the averaged and switching models are in good agreement with the experimental data, but the errors of the averaged model is larger than those of the switching model. The averaged model is proper to the relatively larger errors of simulation results with the faster simulation time, and the switching model is proper to the more exact results with the slower simulation time.

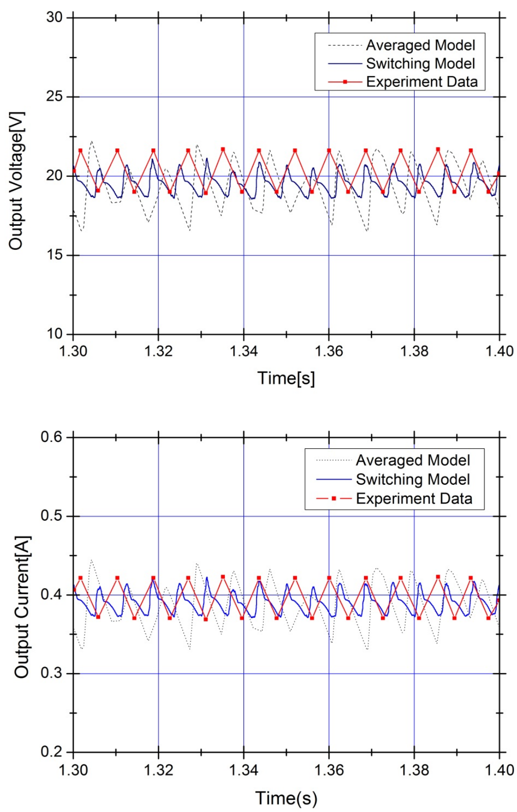

Fig. 10. Comparison between the simulation and experiment data of (a) output voltage and (b) output current of the application circuit for 8W LED driver [8].

IV. CONCLUSIONS

In summary, we introduced the PSPICE modeling technique of a commercial LED driver IC (TOP245P) and PC817A optocoupler to design and simulate the SMPS (applicable to LED driver). An ABM model of the TOP245P IC including the shunt regulator, UV detection, OV shut-down and SR flip-flop developed by using PSPICE was proposed. The empirical equation of PC817A CTR was fitted from the datasheet of PC817A. To verify the validity of the proposed modeling technique, two types of SMPSs, as two examples of application circuit, are simulated with the averaged and switching models. The simulation results by the proposed PSPICE models are in good agreement with those in the data sheet and an experiment data. By comparing the simulation results of the averaged and switching model, we propose the simulation method: the averaged model is proper to the case when the fast simulation results with relatively larger errors would be obtained and the switching model is proper to the case when the more exact results with the slower simulation time would be obtained.

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