

## Sequential-Color Voltage-Adaptable RGB-LED Backlight Driving System with Local Dimming Control for LCD Panels

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**Abstract**—Higher luminance efficacy, faster response, lower power consumption, longer operation life, wider color gamut and environmental issues makes RGB LED backlight driving system suitable for high end LCD applications. In this paper, a sequential-color voltage-adaptable RGB LED backlight driving system with local dimming control for LCD panels is proposed. Using the topology proposed in this paper, the panel can be divided into 4 individual areas. A digitally-controlled multi-phase driving system for RGB LED lamp, a current sharing method, and a human machine interface (HMI) for dimming the backlight module will be presented. The output voltage is adjustable so that RGB LED maintains the desired string current and maximizes the efficiency. Finally, experimental results are presented to validate the effectiveness and correctness of the proposed system. Besides the presented system can successfully drive the RGB LED backlight module, and the color-mixing can be achieved using the developed HMI and driving system.

### I. INTRODUCTION

Nowadays, liquid crystal display (LCD) panels are widely used in applications such as monitors, notebooks and televisions [1]-[2]. LCD requires backlight units because the liquid crystal devices themselves do not emit light inherently. Among the various backlight technologies, the RGB LED backlight has the advantages such as wider color gamut, higher luminance efficacy, faster response, lower power consumption, longer operation life and lower environmental issues; therefore, RGB LED backlight has been regarded as the best potential backlight source for next-generation displays [3]-[7].

In this paper, a sequential color voltage-adaptable RGB LED backlight driving system with local dimming control for LCD panels is proposed. Using the topology proposed in this paper, the backlight can be divided into 4 individual areas. A digitally-controlled four-phase interleaved driving system for RGB LED lamp, a current sharing method, and a human machine interface (HMI) for dimming the backlight module is presented. The output voltage is self-adjusted so that RGB LED maintains the desired string current. Because the voltage across the linear current regulators in the system is the minimum voltage, the driving system efficiency is maximized. Finally, experimental results are presented to validate the effectiveness and correctness of the proposed system. According to the experimental results, the presented system can successfully drive the RGB LED

backlight module, and the dimming and color-mixing function can be achieved using the developed HMI and driving system.

### II. SYSTEM CONFIGURATION

Fig. 1 shows the block diagram of the proposed system. From Fig. 1, the whole system can be divided into three major parts: RGB LED backlight module, digitally-controlled backlight driving system and a local dimming control unit. Detailed descriptions about each part will be given in the following sections:

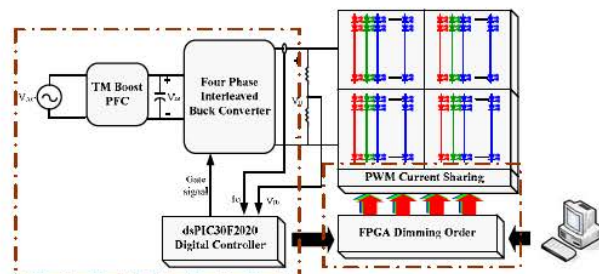


Fig. 1. Block diagram of the proposed system

a. RGB LED backlight module: in order to verify the local dimming control concept of the proposed system, a prototype of RGB LED backlight module is constructed. The presented backlight module uses 240 T5050ORGB-6 RGB LEDs from Yo Hua Corp. The RGB LED used in this paper is a 0.2 W LED. The luminous intensity is 2000/2000/1000 mcd for red/green/blue LED. The 240 RGB LEDs are arranged in four areas, and each area has three strings which has twenty LEDs.

b. Digitally-controlled backlight driving system: the digitally-controlled multi-phase driving system includes a power factor corrector (PFC) front stage, a four-phase buck converter and a digital control unit for receiving the dimming command from the external image processing units and providing the gating signals of the four-phase buck converter. The detailed description of the digitally-controlled backlight driving system will be provided in section III.

c. Local dimming control unit: the aforementioned backlight driving system can only provide a voltage source for RGB LED driving. To achieve the goals of individual local dimming control, the dimming command of each area should be provided. The commonly used PWM dimming

technique is adopted in this paper. The proposed local dimming control unit can receive the dimming command of each area from the digital controller, and generate the required PWM signal for each RGB LED string. Fig. 2 shows the PWM dimming circuit used in this paper. From Fig. 2, the linear current regulators is used to provide a constant current source to LED string, and the LED brightness can then be controlled by adjusting the relative ratios of the on time and off time. Since forward current of the LED string is not changed, LED color will not vary with brightness.

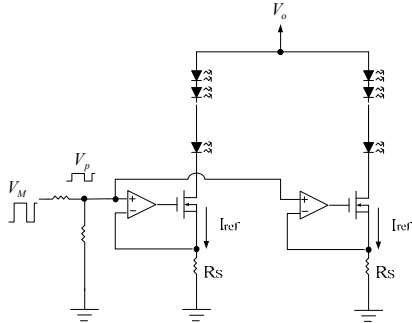


Fig. 2. The diagram of the PWM dimming circuit

### III. DIGITALLY-CONTROLLED BACKLIGHT DRIVING SYSTEM

Fig. 3 shows the block diagram of the proposed digitally controlled backlight driving system. From Fig. 3, the digitally-controlled backlight driving system can be divided into three major parts: DSP-based digital controller, power factor correction (PFC) stage and a four-phase buck converter power stage. Detailed descriptions about each part will be given in the following sections:

a. Digital controller: the digital controller reads the dimming command input from the image processing unit, and then performs the digital control of the four-phase buck converter power stage. Since the proposed backlight driving system can control the luminance of the panel in 4 areas individually according to the luminance requirement of the video input; therefore, the consumption of power can be reduced and the dynamic contrast ratio can be enhanced. The proposed main controller is implemented using the dsPIC30F2020 device from Microchip Corp. The digital controller also reads the status of the power converter module (such as output current and voltage) for implementation of control and protection functions.

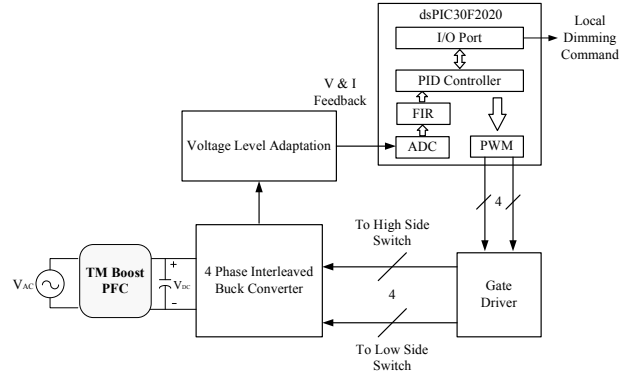


Fig. 3. Block diagram of the digitally controlled driving system

b. PFC stage: the power stage is driven by the rectified voltage source, which usually induce harmonic current distortion and electromagnetic interference. To solve these problems, a PFC stage is added at the front end in order to comply with international standard such as IEC 61000-3-2 Class C appliances. In this paper, the PFC stage is implemented using the L6561 control IC from SGS-Thompson Corp, and is operated in transition mode (TM).

c. Four-phase buck converter: the power stage utilized in this paper uses an multi-phase interleaved buck converter topology. Fig. 4(a) shows the four phase buck converter used in this proposed system. Interleaving greatly reduces the current ripples to the output capacitors, which in turn reduces the steady-state output voltage ripples, making it possible to use very small inductances to improve transient responses. The cancellation effect of interleaving on the individual peak-to-peak inductor ripple current can be expressed as (1),

$$K_N(D) = \frac{N(D - \frac{m}{N})(\frac{m+1}{N} - D)}{D(D-1)} \quad (1)$$

where D is the duty cycle, N is the phase number and  $m = \text{floor}(N \cdot D)$ .

As shown in Fig. 4, the backlight driving circuit utilized in this paper is a bidirectional power converter operated in discontinuous conduction mode (DCM). In buck-mode operation shown in Fig. 4(b), the power converter supplies the corresponding voltage for driving RGB LED backlight module. In boost-mode operation shown in Fig. 4(c), the residual energy in the output capacitor will be removed such that the voltage can be reduced rapidly. Because red, green and blue LED has different forward voltage, the output voltage of the power converter has to change to attain the required RGB LED string voltage. The proposed driving system with adaptive output voltage is achieved by changing the operation mode of converter.

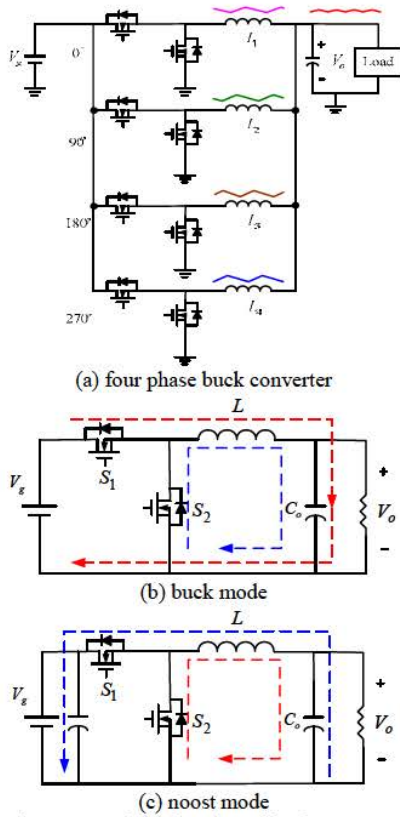


Fig. 4. Four phase interleaved buck converter

#### IV. SOFTWARE CONFIGURATION OF THE PROPOSED SYSTEM

As described in section III, the proposed power stage operates in different mode to achieve the output voltage adaption. Fig. 5 illustrates the operating sequences of the proposed backlight system. It should be noted that the PWM frequency should be higher than 60 Hz to avoid flicker. From Fig. 5, the power converter will drive the red, green and blue LED string in sequence. Since the forward voltages of these LEDs are different, the output voltage of the power converter has to change accordingly. In this paper, the input voltage is 240 V and the output voltages required to drive 20 red, green and blue LEDs are 48 V, 72 V and 72 V, respectively. Note that boost mode is required to quickly reduce the output voltage from 72 V to 48 V when the driving signal shifts from En\_B to En\_R. In Fig. 5, the En\_R, En\_G and En\_B are synchronous signals which can be used to synchronize the operation of dsPIC (which controls the output voltage of each LED string) and FPGA (which generate the required PWM dimming command for each LED string). Fig. 6 shows the flowchart of the proposed digital control algorithm. The switching frequency of the proposed system is chosen as 50 kHz; therefore, the digital filter and digital controller is performed every 20  $\mu$ s. The digital filter used in the proposed system is a 48-order

finite impulse response (FIR) filter. The equation describing a FIR filter can be expressed as(2),

$$y[n] = \sum_{k=0}^{T-1} a_k x[n-k] \quad (2)$$

where x is the filter input, y is the filter output and  $a_k$  is the corresponding coefficient of the designed FIR filter. The digital controller utilized in this paper is a conventional PID controller; the digital control algorithm can be designed as(3),

$$U_i(n) = K_p E_i(n) + K_i E_i(n-1) + K_d E_i(n-2) + K_3 U_i(n-1) + K_4 U_i(n-2) \quad (3)$$

where E(n) is the error signal and U(n) is the input signal.

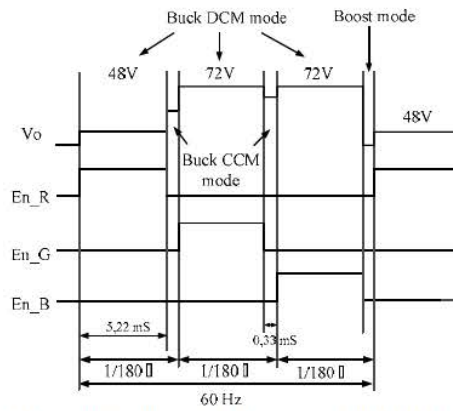


Fig. 5. Operating sequences of the proposed backlight system

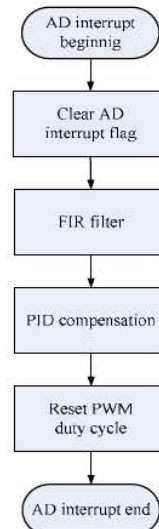


Fig. 6. Flowchart of control algorithm

To dim a four-area LCD backlight with RGB LEDs, 12 PWM signals are required. Therefore, an FPGA is adopted to assist the dsPIC microcontroller and provide the 12 PWM dimming signals. Fig. 7 shows the software configuration of

the local dimming controller. From Fig. 7, the local dimming controller receives the dimming commands from the HMI via RS-232 communication protocol, and compares them with sawtooth signals to generate PWM signals. Since the PWM dimming should synchronize with the output voltage, the local dimming controller also receives the synchronous signals En\_X. Fig. 8 shows the HMI developed for the proposed system.

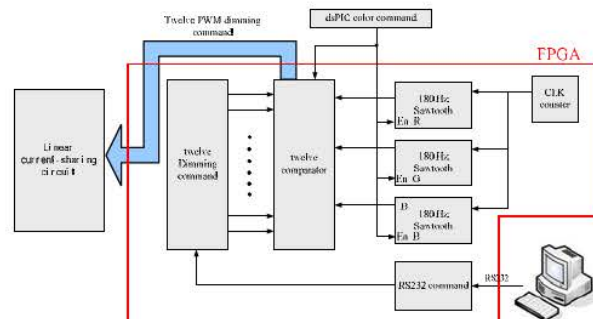


Fig. 7. Software flowchart of the local dimming controller

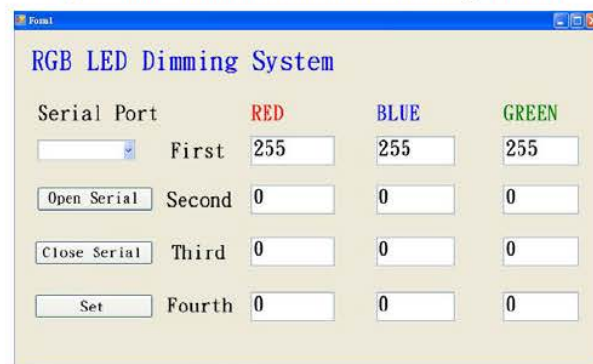


Fig. 8. Human machine interface of the proposed system

## V. EXPERIMENTAL RESULTS

In order to verify the correctness of the proposed system, some experiments are carried out. Due to limited space, only selected waveforms are displayed in this section. Fig. 9 shows the measured efficiency and power factor for the developed PFC. From Fig. 9, the efficiency is higher than 92 % and the power factor is higher than 0.89. Fig. 10 shows the inductor currents and gating signals of a four phase buck converter. From Fig. 10, the gating signals are properly interleaved with 90° separation. Fig. 11 shows the measured output voltage of the power supply circuit. From Fig. 11, the output voltage can follow the forward voltage requirement of the RGB LED string. Fig. 12 shows the picture of the LED backlight panel under certain dimming command. In Fig. 12, the dimming commands for each area are : I:( R=100 %, G=100 %, B=100 %), II:( R=100 %,G=0 %,B=0 %), III:( R=0 %,G=0 %,B=100 %), IV:( R=0 %,G=100 %,B=0 %).

## VI. CONCLUSION

In this paper, a sequential-color voltage-adaptable RGB LED backlight driving system with local dimming control for LCD panels is proposed. The presented system consists of a LED backlight module, a voltage-adaptable digitally-controlled power source and a local dimming control signal generation unit. Multi-phase power converter features the advantages such as low output voltage/current ripple; therefore it is suitable for LED driving since the LED requires constant current to drive. Adjust output voltage based on the required headroom for the LED outputs can optimize the efficiency of the driving system. A local dimming control unit is also proposed in this paper, using the proposed unit, the brightness and color of each area can be controlled individually, this will improve the contract ratio as well as energy efficiency. In order to verify the correctness of the proposed technique, a prototyping system is developed in this paper. According to the experimental results, the power conversion efficiency of the whole proposed system is higher than 83 % and the goal of individual local dimming control and adaptable output voltage can be achieved.

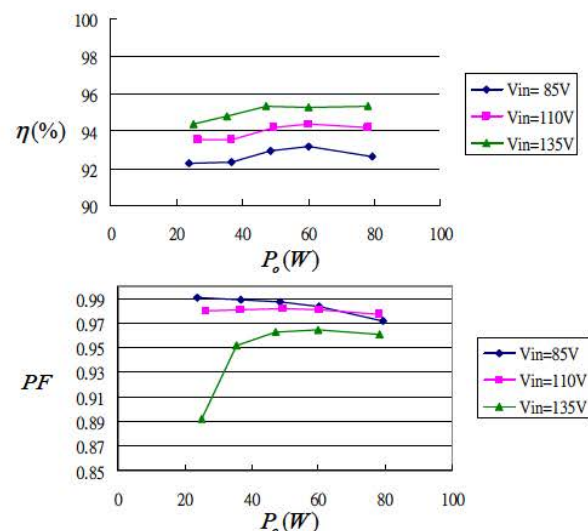
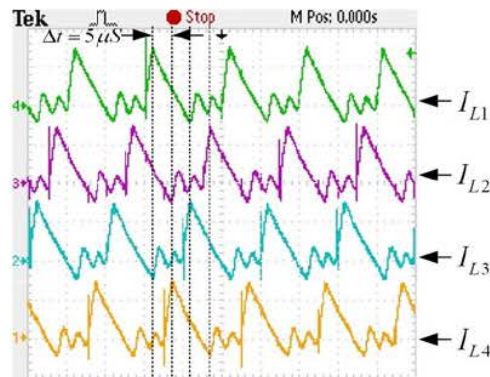
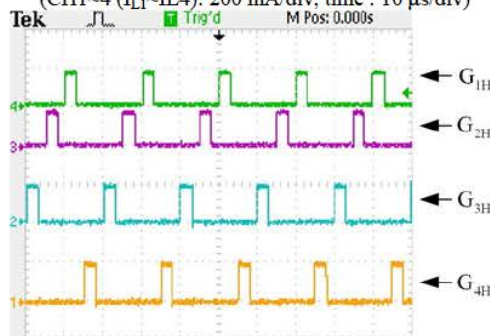


Fig. 9. Measured efficiency and power factor for the developed PFC



(a) inductor current waveform

(CH1~4 ( $I_{L1} \sim I_{L4}$ ): 200 mA/div, time : 10  $\mu$ s/div)

(b) gating control signals

(CH1~4 ( $G_{1H} \sim G_{4H}$ ): 5 V/div, time : 10  $\mu$ s/div)

Fig. 10. Measured waveforms for four-phase buck converter

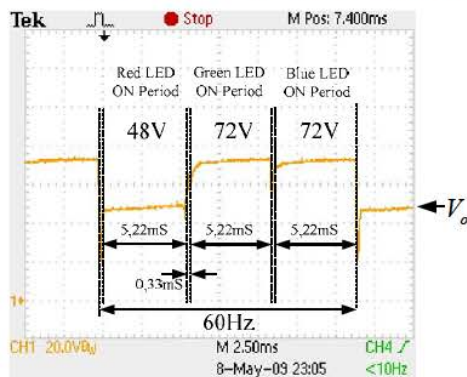


Fig. 11. Measured waveforms for four-phase buck converter

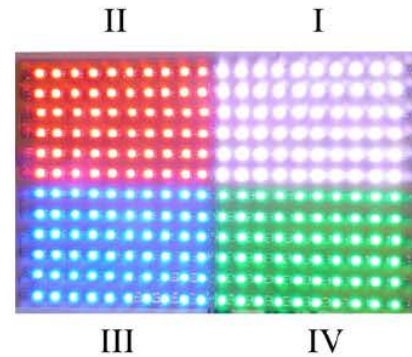


Fig. 12. Photo of the proposed system

## REFERENCES

- [1] Y. H. Liu, "Design and implementation of an FPGA-Based CCFL driving system with digital dimming capability," *IEEE Trans. Ind. Electron.*, Vol. 54, No. 6, pp. 3307–3316, Dec. 2007.
- [2] H. J. Chiu, S. J. Cheng, "LED backlight driving system for large-scale LCD panels," *IEEE Trans. Ind. Electron.*, Vol. 54, No. 5, pp. 2751–2760, Oct. 2007.
- [3] C. C. Chen, C. Y. Wu, Y. M. Chen, T. F. Wu, "Sequential-color LED backlight driving system for LCD panels," *IEEE Trans. Power Electron.*, Vol. 22, No. 3, pp. 919–925, May 2007.
- [4] X. Qu, S. C. Wong, C. K. Tse, "Color control system for RGB LED light sources using junction temperature measurement," in *Proc. 2007 IEEE Industrial Electronics Society Conf.*, pp. 1363–1368.
- [5] J. H. Souk, J. Lee, "Recent picture quality enhancement technology based on human visual perception in LCD TVs," *J. Display Technol.*, Vol. 3, No. 4, pp. 371–376, Dec. 2007.
- [6] Y. F. Chen, C. C. Chen, K. H. Chen, "Mixed color sequential technique for reducing color breakup and motion blur effects," *J. Display Technol.*, Vol. 3, No. 4, pp. 377–385, Dec. 2007.
- [7] T. F. Wu, C. C. Chen, C. Y. Wu, P. C. Lu, Y. R. Chen, "Sequential-color LED backlight driving system for LCD panels with area control," in *2007 IEEE Power Electronics Specialists Conf.*, pp. 2947–2952.