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 dimming and color-mixing function 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:

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 T5050RGB-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
directed 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.

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),

\[ K_y (D) = \frac{N (D - \frac{m}{N}) (\frac{m + 1}{N} - D)}{D (D - 1)} \]  

where D is the duty cycle, N is the phase number and
m=floor(N • 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.
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 adaptation. 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 μs. 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:

\[ y[n] = \sum_{k=0}^{T-1} a_k x[n-k] \]  

(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:

\[ U_i(n) = K_e E_i(n) + K_e E_{i-1}(n) + K_e E_{i-2}(n) + K_d U_{i-1}(n-1) + K_d U_{i-2}(n-2) \]  

(3)

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

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.

![Image of the local dimming controller flowchart]

**Fig. 7. Software flowchart of the local dimming controller**

**RGB LED Dimming System**

<table>
<thead>
<tr>
<th>Serial Port</th>
<th>RED</th>
<th>BLUE</th>
<th>GREEN</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>255</td>
<td>255</td>
<td>255</td>
</tr>
<tr>
<td>Open Serial</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Close Serial</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Set</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fourth</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**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 contrast 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. 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


