LED Voltage Regulation for TV LED Backlighting

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Introduction 3
LED Forward Current (I_F) vs. Forward Voltage (V_F). 4
LED String with a Current Sink 4
Boost Converter Driving LED Array 6
Dropout Voltage. 8
Startup 8
Sample and Hold During ON/OFF. 8
Skyworks TV LED Backlight Drivers and Related Devices 9

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Introduction

There are large arrays of LEDs located behind the LCD panel in a typical LCD TV LED backlighting system as shown in Figure 1. In this array are a large number of parallel channels of LEDs connected in series depending on the size of the TV and the type of backlighting, for example edge backlighting (less LEDs but more in series) or direct backlighting (more LEDs in parallel). The LED voltage (V_{LED}) is provided by the White LED Backlight Driver Board to each LED channel and is regulated to a level needed by the highest voltage required to maximize the light output of each LED string.

Depending upon the power supply requirements determined by the number of LEDs in the string or grouping of parallel LED strings, the up-stream power source for the LED backlight driver board may be a DC/DC step-up boost converter, a DC/DC step-down converter or more commonly an AC/DC converter. In the case where supply voltage is lower than the required VLED, a step-up boost converter will be used. As an example, a LED boost converter LED backlighting system will be described in detail in this paper for a direct backlighting application, however the theory of operation will also apply to both the step-down converter and AC/DC converter situation.

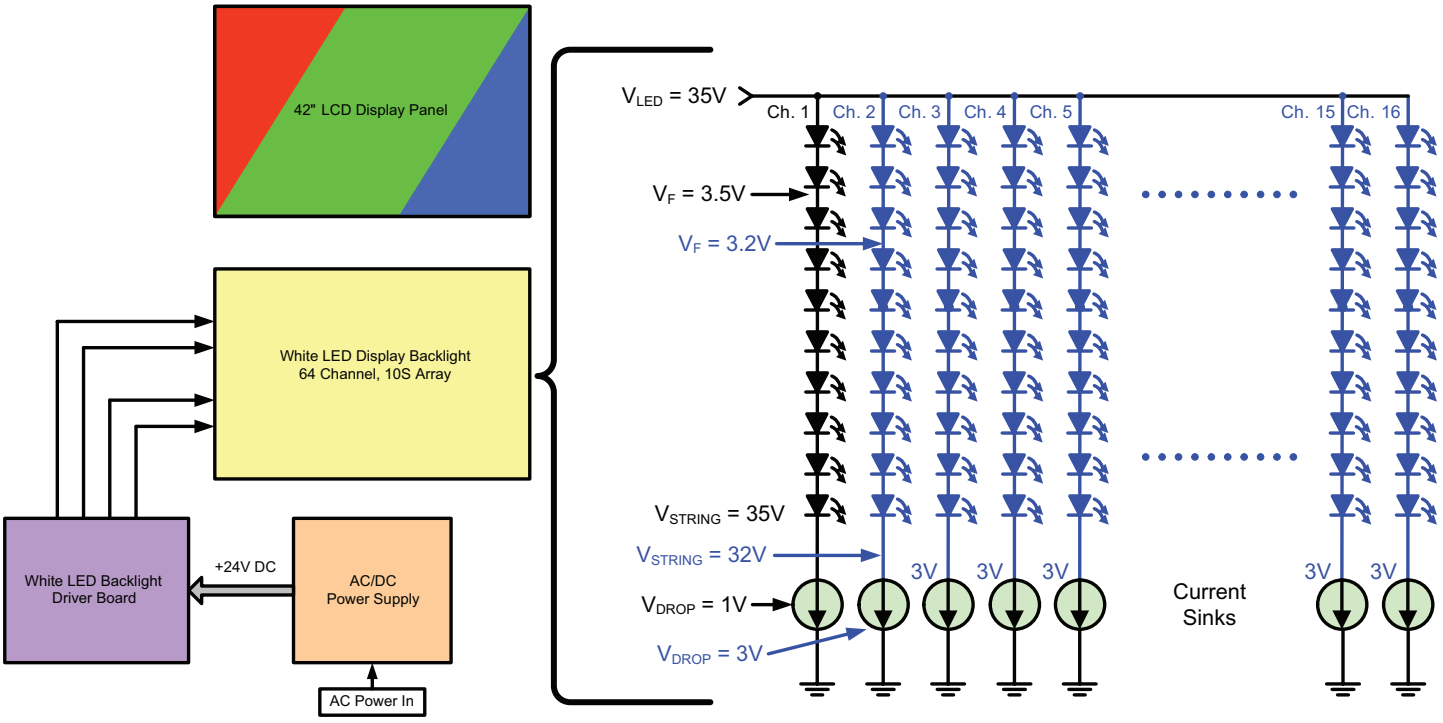


Figure 1: Simplified LED Backlight LCD TV Block Diagram and Direct-type LED Array.

LED Forward Current (I_F) vs. Forward Voltage (V_F)

High brightness LEDs used in LCD backlighting require high LED current which also equates to higher LED forward voltage. A typical relationship between TV backlight LED forward current (I_F) and forward voltage (V_F) is illustrated in Figure 2. For example, if a user wants to set the LED current to 80mA maximum, a minimum of 3.65V forward voltage must be provided to each LED in the string. If the power supply can only provide 3.6V to each LED, then the maximum LED current is limited to 74mA.

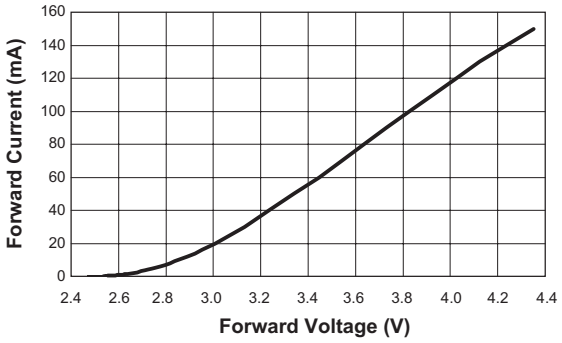


Figure 2: Typical LED Forward Current (I_F) vs. Forward Voltage (V_F).

LED String with a Current Sink

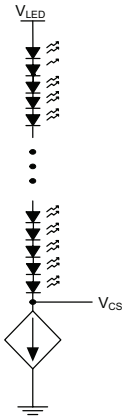


Figure 3: Series LED String with Current Sink Control.

Figure 3 shows an LED backlight string with a controller which sets the brightness level with current sinks. V_{CS} must be large enough in order for the current sink to operate properly. The lowest V_{CS} of all of the LED strings will be the LED string with the largest composite forward voltage. The regulated V_{LED} must be greater than V_{CS} plus the highest composite LED forward voltage. If this condition is met, all the strings will have V_{CS} greater than the dropout voltage (see the Dropout Voltage section of this document) and thus all current sinks will operate properly. In Figure 4, the LEDs in Ch. 1 (black) have a V_F equal to 3.5V and the LEDs in Ch. 2 have V_F equal to 3.2V. So if the highest voltage condition is met, each LED current sink will have sufficient headroom to provide accurate current to set the light output correctly. If V_{LED} is regulated too low, the highest voltage LED string will be out of regulation and enter dropout, minimizing output current. On the other hand, if V_{LED} is regulated too high, each LED string will have more than enough regulated voltage and good output current accuracy but unnecessary power will be dissipated across the current sink, resulting in extra power and heat dissipation.

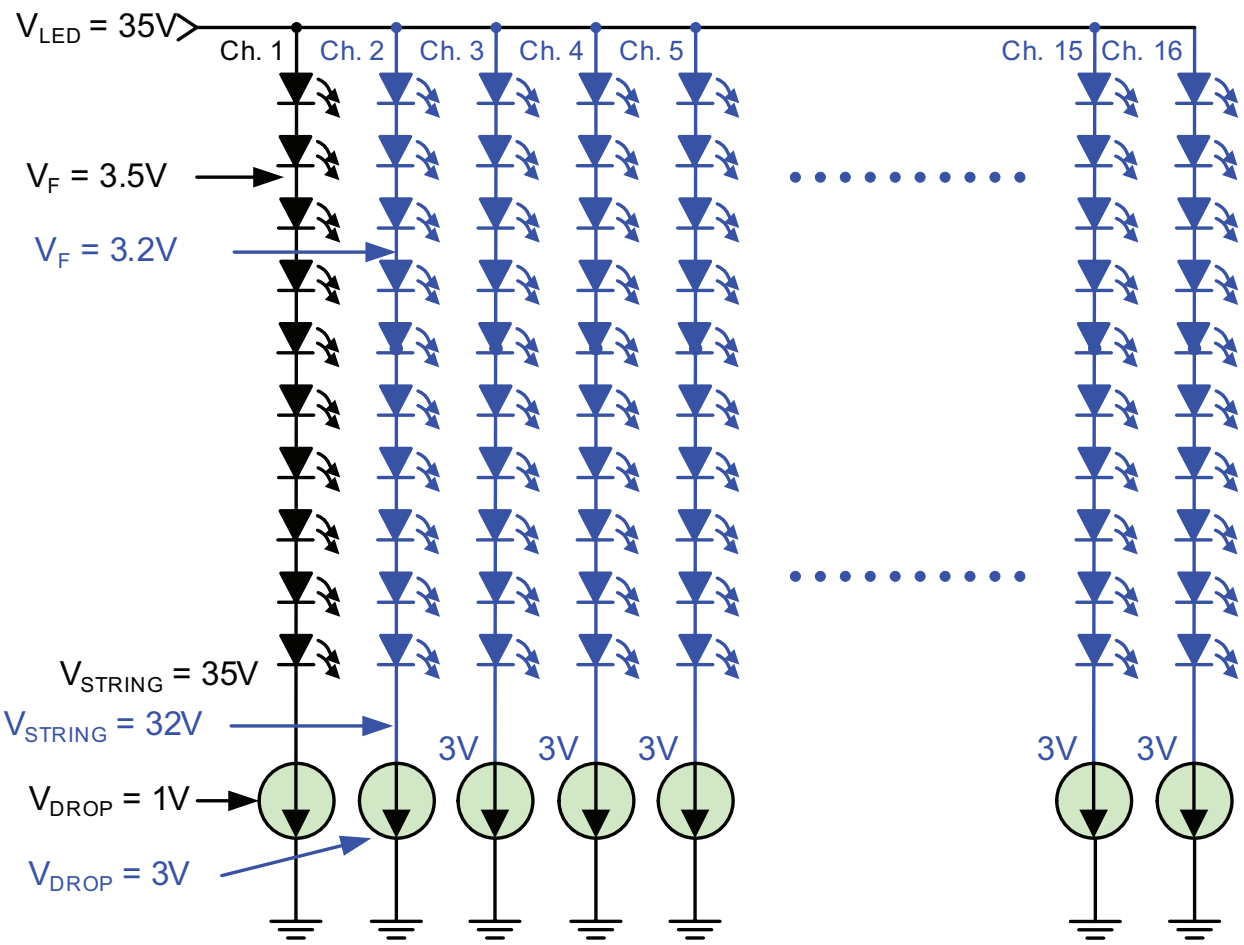


Figure 4: Example LED Array, 16 Channels of 10 LEDs Connected in Series.
The LEDs in this example need 70mA to effectively backlight the LCD panel, but the Ch.1 LEDs have a higher V_F than Ch. 2, requiring 35V to get 70mA.

Boost Converter Driving LED Array

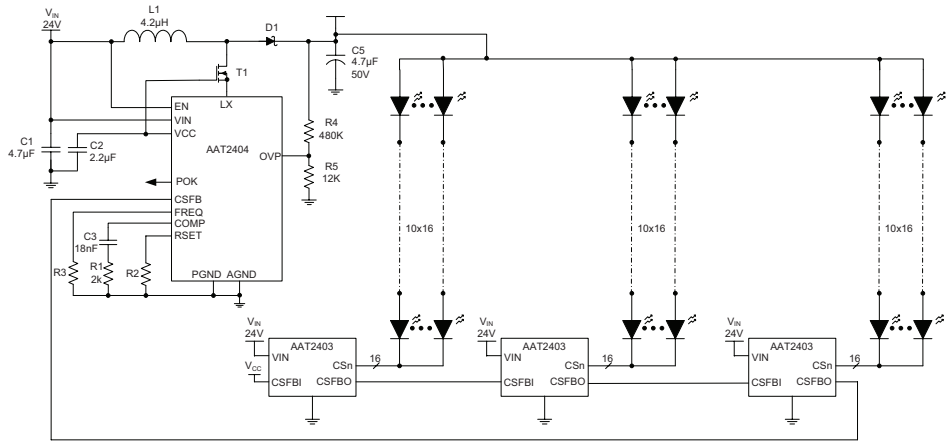


Figure 5: Example LED Backlight with Boost Controlled V_{LED}.

In a system where supply voltage (V_{IN}) is lower than V_{LED}, a step-up boost converter is used to provide power to the LED strings. As shown in Figure 5, the output voltage of the boost converter drives all the LED strings. The feedback signal CSFBO connected to CSFB on the boost converter provides the lowest V_{CS} level from all the LED strings and also controls how the V_{LED} voltage is regulated.

When the CSFB voltage is lower than the dropout voltage that is necessary for the LEDs to operate correctly, the step-up converter will boost the V_{LED} level. However, when the CSFB voltage is higher than the dropout voltage, the step-up converter will stop boosting V_{LED}. During this time, the LED current is provided by the boost output capacitor (C5). This boost is set as a forced PWM system, so the pass switch (T1) will turn on with a minimum on-time (unless current limit or OVP is reached) to provide output current to the LEDs as well. At some point when the required LED current is higher than the current provided by the boost capacitor and the minimum on-time of T1, the V_{LED} will start to drop and CSFB will go below the dropout voltage. At that time, the step-up converter will start boosting the V_{LED} voltage level.

Normal operation of the AAT2404 and AAT2403 is shown in the scope shots in Figures 6, 7 and 8. The OVP setting on the boost is calculated to be at least 10% greater than the total forward voltage of each LED string plus the minimum V_{CS}.

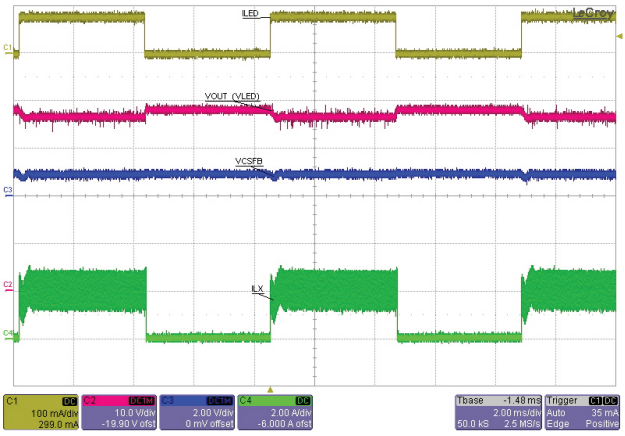


Figure 6: Normal Operation of AAT2404 and AAT2403 with all Current Sinks (CS) in the AAT2403 set to 100mA, 80% DOT Correction (80mA) and 50% Gray Scale, No Delay.
While all CS are OFF, the V_{OUT} level of the AAT2404 is at the OVP level. While all CS are ON, the V_{OUT} level of the AAT2404 is regulated to the voltage required for the LEDs to sink 80mA.

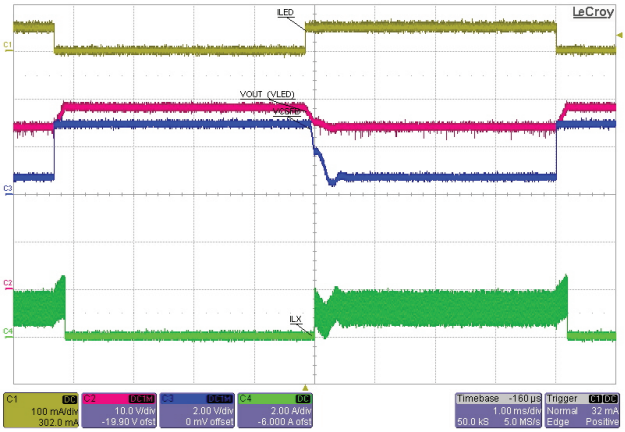


Figure 7: Normal Operation of AAT2404 and AAT2403 with all Current Sinks (CS) in the AAT2403 set to 100mA, 50% DOT Correction (50mA) and 50% Gray Scale, No Delay.
While all CS are OFF, the V_{OUT} level of the AAT2404 is at the OVP level. While all CS are ON, the V_{OUT} level of the AAT2404 is regulated to the voltage required for the LEDs to sink 50mA.

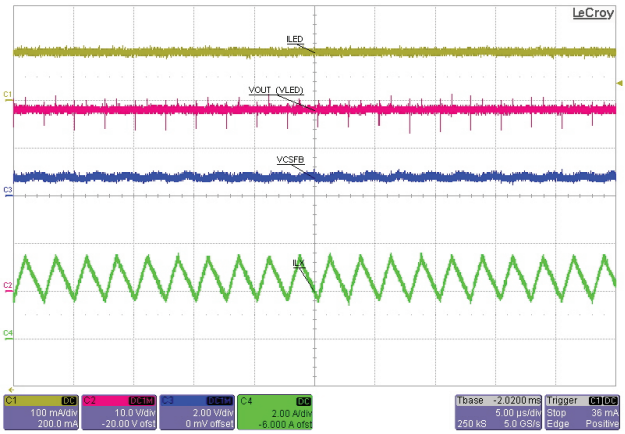


Figure 8: Normal Operation of AAT2404 and AAT2403 while AAT2404 is being set to 100mA, 100% PWM Duty Ratio (fully turned on at 100mA).

Dropout Voltage

The dropout voltage is the voltage level when the current sinks in the backlight controller start to go out of current regulation. This is also the voltage level used as the reference for the power supply converter. For a current sink to operate with good accuracy, V_{CS} has to be greater than the dropout voltage. As shown in Figure 9 for the AAT2403, the dropout voltage will be different depending upon the maximum current requirement and is proportional to the current sink current (I_{LED}) and R_{SET} value (R2 in Figure 5). When using the AAT2404 boost converter, the same values of R_{SET} should be used for both AAT2403 and AAT2404. However for a stand alone power supply working with AAT2403, the dropout voltage is the reference voltage for the converter which should be determined by the R_{SET} value.

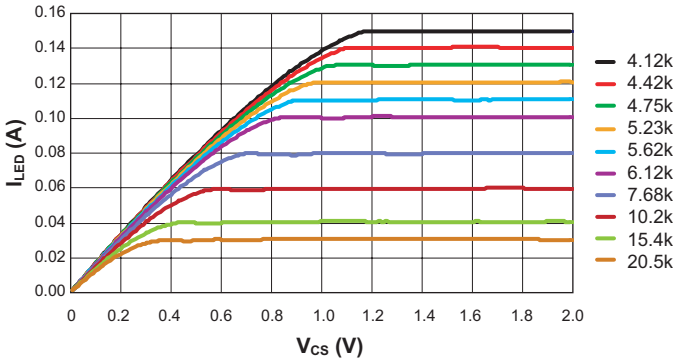


Figure 9: Dropout Voltage is the V_{CS} Voltage Level Point where I_{LED} starts to Roll Off (100% PWM Duty Ratio and 100% DOT).

Startup

During startup, since LED strings are not yet turned on, the CSFB voltage is at 0V, so the boost converter will start stepping up VLED. In the case of the AAT2404, the startup voltage soft starts to 90% of the OVP voltage. This provides enough voltage level for VLED when the first LED string turns on. The boost converter will not step up full VLED until the CSFB voltage is below the reference (dropout) voltage.

Sample and Hold During ON/OFF

In some systems it is desirable to maintain the operating LED voltage when the LED current sinks are OFF. When the LEDs are OFF, the voltage across the LED string decreases. When the LED string turns off, the current sink voltage will rise. Without a sample and hold technique, the LED voltage will regulate down in order to drive the current sink voltage to the regulation point even though the LED string is OFF. Since there is no power consumed when the LED string is off, regulating the current sink voltage during the OFF time of the LED string is unnecessary. A potentially unwanted effect of regulating the LED voltage during the OFF time is that additional time is necessary to establish the proper LED voltage when the current sink is turned back on as the LED voltage slews to the required voltage level. During this time, the current in the LED string will not be regulated and will tend to be less than the final desired LED current level.

For the AAT2404, when the external current sinks are ON, the CSFB is regulated to the internal reference (dropout) voltage. When the external current sinks are OFF or CSFB voltage is greater than an internal set voltage (2.5V), the LED voltage is determined by the voltage level left on the on the compensation capacitor (C3 in Figure 5) which has been disconnected from the feedback loop. During this OFF time, since the inductor current is proportional to the compensation capacitor's voltage, VLED will not decrease and will be either held or increase slightly until required to turn on the LEDs.

In the extreme case when no LED current is drawn, V_{LED} could be charged as high as OVP, which will provide enough voltage level headroom for the next current sink to turn back on. In this case, V_{LED} will operate between OVP and the minimum V_{LED}. This will eliminate the unwanted effect of converter response time and current slewing when the LED is turned back on again.

To disable the sample and hold feature on the AAT2404, a 10k resistor can be inserted from CSFB to ground. V_{LED} will be regulated even when the current sinks are OFF, causing current slewing during turn on.

Skyworks TV LED Backlight Drivers and Related Devices

The following devices have a Voltage mode CSFBO output (and input for cascading ICs):

- AAT2401
- AAT2402S
- AAT2403

The voltage mode feedback of each of these ICs is intended for direct interfacing to the AAT2404 boost converter or in master/slave operation with the AAT2400 or AAT2402M.

When using these devices as a single driver or if the device is the first IC in a cascaded chain of ICs, then the CSFBI input pin should be terminated to VCC to remove it from the system. The reference voltage (dropout voltage) is unique to each external power supply and can be determined as described in the Dropout Voltage section and in Figure 9.

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