Application Report
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High-Efficiency AC-DC TV Power Solutions: Proposing an Intelligent LED Backlight Driving Scheme

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ABSTRACT

LCD televisions designed with LED backlight are continuing to grow in popularity compared to conventional TV architectures that use cold cathode fluorescent lamp (CCFL) bulbs because of the supreme feature set that these systems offer: greater brightness, higher contrast ratios, stylish thin designs, and significantly lower power consumption. To derive the full potential of the LED-based LCD backlight technology, however, it is important to achieve both good thermal design and precise backlight ON-OFF control for good picture quality by using the greater color gamut and higher contrast ratio of the LED, and suppressing LCD TV motion blur.

This application note presents novel power architectures with regard to the ac-dc total power supply for an LCD TV design, achieving higher power efficiencies and lower cost. The revolutionary iHVM™ mechanism enables intelligent LED bias control to minimize power loss. On the other hand, the fast LED drivers provide precise LED ON-OFF control. In this report, two reference designs are discussed. The PMP4298 is the basic topology reference design; this design consists of a primary ac-dc stage, a secondary boost dc-dc converter stage for the LED backlight, and a multi-channel LED driver. The PMP4298A is proposed as an advanced reference design that achieves a much higher efficiency and an overall lower cost by omitting the LED backlight dc-dc secondary stage. The LED driver is instead supplied directly from the ac-dc primary power-based LED backlight solution. Performance results are also presented.

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1 Introduction

Liquid crystal display (LCD) television has become a hot favorite for consumers worldwide, mostly as a result of the superior technology adopted by the industry in the manufacturing processes for these systems. Since it was first introduced to the market, periodic improvements have been made in response to user comments and complaints. Many new techniques continue to improve the performance of these units. Some of these techniques are unique to LCD television; light-emitting diode (or LED) backlighting is one of these improvements.

This new backlight design has been acknowledged as having enormous potential for television technology and architecture. Some experts even theorize that LED backlight will eventually replace all other backlight techniques in the near future. LEDs are now widely used in many LCD televisions regardless of size. LED implementation facilitates saturated colors and superior color reproduction. Compared to other methods for backlights, LEDs are the most popular system because of these advantages, among others:

1. **Long lifetime:** With a life span of 50,000 hours or more, LED technology is the most durable backlight system in the television industry.
2. **Contrast ratio:** The fast switching capability is one of the biggest advantages of solid-state backlight compared to conventional backlight such as CCFL bulbs. In an LCD TV, this capability translates into a dynamic contrast ratio, which is an important specification for an LCD TV set to achieve better picture quality.
3. **Wide color gamut:** LED backlight has the potential to provide a superior, wide range color gamut, especially with RGB LED backlight. Even with WLED backlight, color purity is much better than with CCFL backlighting; this benefit also increases the overall system picture quality.
4. **Brightness:** The light efficacy of LED technology is continuously improving, almost at the rate of twice per decade. LCD TV makes full use of this benefit, not only for picture quality improvement or lower power consumption, but also in areas such as 3D-TV (theoretically, the brightness is halved to 2D-TV) and using LCD TVs out-of-doors.
5. **TV design flexibility:** Because the LED itself has a smaller dimension compared to traditional CCFL backlighting, stylish new TV designs are achievable; for example, an edge-lit, wall-mounted TV set has a thickness of less than 10 mm. These types of innovations are promoting new styles in many homes.
6. **Low power consumption:** As noted earlier, the LED has much higher light efficacy compared to conventional technologies. Therefore, an LED backlight TV set has lower power consumption. EnergyStar v4.0/v5.0 and California Energy Commission (CEC) standards control power consumption performance for LCD TVs with different size panels. For example, for a 42-inch panel, the EnergyStar v4.0 (May 2010) regulation required that the maximum input power should be less than 115 W; the CEC Tier1 (January 2011) standard requires a maximum input power of less than 183 W. Conventional CCFL backlight technology is unable to meet these regulations; as a result, LED backlight technology is the first choice for system designers.
7. **Environmentally friendly TV:** An LED backlight LCD TV set contains no mercury, so it is easier to dispose of and more easily recycled than other types of LCD TVs. This is the primary reason that many environmentalists also support LED TVs over other TV technologies.

Considering these benefits, as well as others, LED backlight has become the mainstream technology and is quickly replacing conventional CCFL backlight designs for LCD TVs. Because of the low cost and easy design, edge-type LED backlight structures have been widely used in recent LED backlight TVs. Figure 1 shows the typical power conversion architecture for edge-type LED backlight TVs.

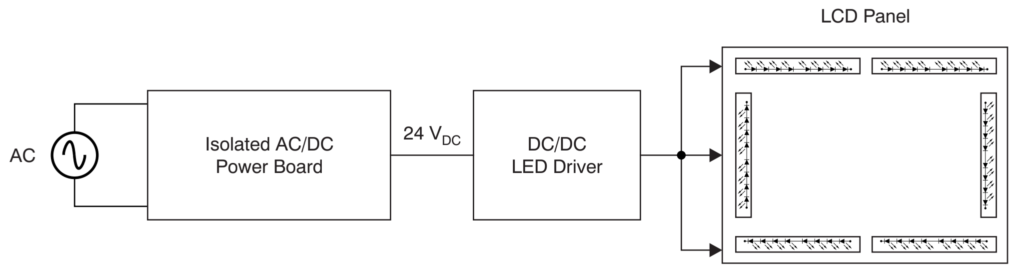


Figure 1. Edge-Type LED Backlight LCD TV Power Conversion Scheme

This topology uses a switching, high-voltage boost dc-dc converter for each LCD string. It is very common for a switching boost dc-dc converter used in a multi-string configuration to generate electromagnetic interference (EMI) problems, because multiple switching LED drivers generate additional high-frequency switching, differential-mode (DM) noise at this stage, and therefore affect the measured results of both conducted and radiated EMI in the TV power system. An increased EMI design effort—for example, an RC snubber network at the switching node or an EMI filter at the output side—is then required in order to comply with the EMI standards.

Instead of this additional constraint, a linear constant-current regulator topology is sometimes selected. This topology does not generate any high-frequency switching noise; therefore, it is the perfect solution for EMI designs with a reduced BOM cost target. However, the power dissipation of the conventional linear driver approach is normally more excessive than the multiple dc-dc converter approach, because it lacks an LED bias, dc-dc voltage optimization mechanism.

This document introduces several innovative topologies for LED backlight TV with two power reference designs (the PMP4298 and PMP4298A) using the TLC5960, an eight-channel, intelligent linear LED driver from Texas Instruments. The TLC5960 intelligent headroom voltage monitor creates a dedicated, closed feedback loop to automatically optimize the LED bias voltage by using the forward voltage information of the LED strings. This application note shows not only a dc-dc LED bias stage but also a direct LED bias control from the primary side ac-dc LLC converter output, without any boost dc-dc required in front of the LED driver. Both topologies can be selected based on the customer's specific requirements, and contribute to improved system efficiency while also reducing the total BOM cost.

2 Proposed LED Backlight TV Power Architectures

Two power architectures are proposed. First, the basic architecture of a LED backlight TV power supply is analyzed (see Figure 2); then, a more advanced configuration specific to an ac-dc power supply LED backlight architecture is discussed (refer to Figure 3). The PMP4298A should achieve a higher efficiency and lower cost because it omits the unnecessary boost dc-dc stage for the LED backlight bias generation. The PMP4298 also has an additional dc-dc stage, enabling users to easily set the ac-dc output voltage to a certain preferred range. On the other hand, the PMP4298A has no additional stage; the ac-dc output voltage should be set equal to the LED backlight bias voltage variable range, thus achieving higher efficiency and lower cost.

Table 1 presents a brief comparison of the two architectures.

Table 1. Comparison of Two Reference Designs

Characteristic/Feature	Reference Design	
	PMP4298	**PMP4298A**
Primary stage ac-dc design	TM PFC + LLC, Flyback	TM PFC + LLC, Flyback
Secondary stage design	DC-DC + LED Driver with iHVM	LED Driver with iHVM
Front-end boost dc-dc converter	Yes	No
Efficiency	85%	87%
Cost	Medium	Low
Primary stage ac-dc output voltage	48 V	80 V ±10%

Figure 2 shows the basic architecture of a generic, edge-type LED backlight TV power supply. The stage within the dashed line is the LED light bar driver stage. In this topology, the UCC28051 is a boost transition mode (TM) power factor corrector (PFC), which can rectify an ac input line voltage to 380 V_{DC}; the resonant LLC stage UCC25600 regulates the output to 24 V/2 A for an audio amplifier with feedback to the LLC controller, and 48 V for the LED driver input. The flyback with UCC28610 in parallel generates 5 V/3 A for the system board and 5 V/1 A for standby power. In the LED driver stage, the 48-V input voltage requires another front-end boost stage to boost the output voltage to 80 V, which connects to the eight-channel TLC5960 with 20 LEDs at 120 mA per string. This technique is the most common type of current LED backlight; the LLC design is easily implemented. The intelligent headroom voltage monitor (or iHVM™) automatically minimizes the power loss caused by the LED forward voltage change. Only a single additional resistor regulates the boost dc-dc output voltage.

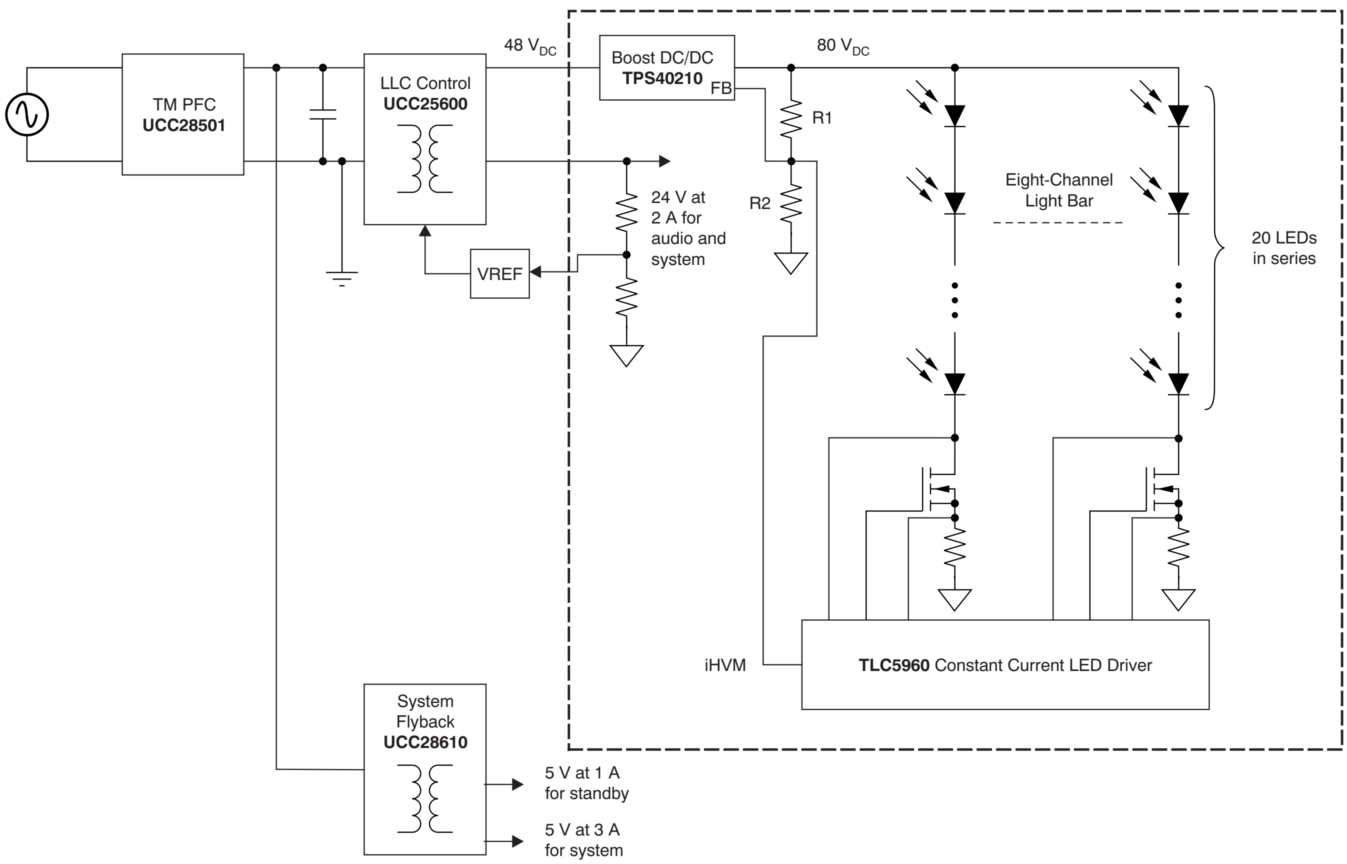


Figure 2. PMP4298: Basic Architecture for LED Backlight LCD TV Power Supply

Figure 3 shows the advanced configuration of an LED backlight LCD TV integrated power supply. The PMP4298A does not have a boost dc-dc converter in front of the LED driver; the iHVM directly controls the primary side ac-dc output voltage based on the feedback information of the headroom voltage on the FETs that drive the LEDs. The voltage for the LLC converter is regulated by both the primary LLC feedback loop and the iHVM feedback loop from the TLC5960 LED driver.

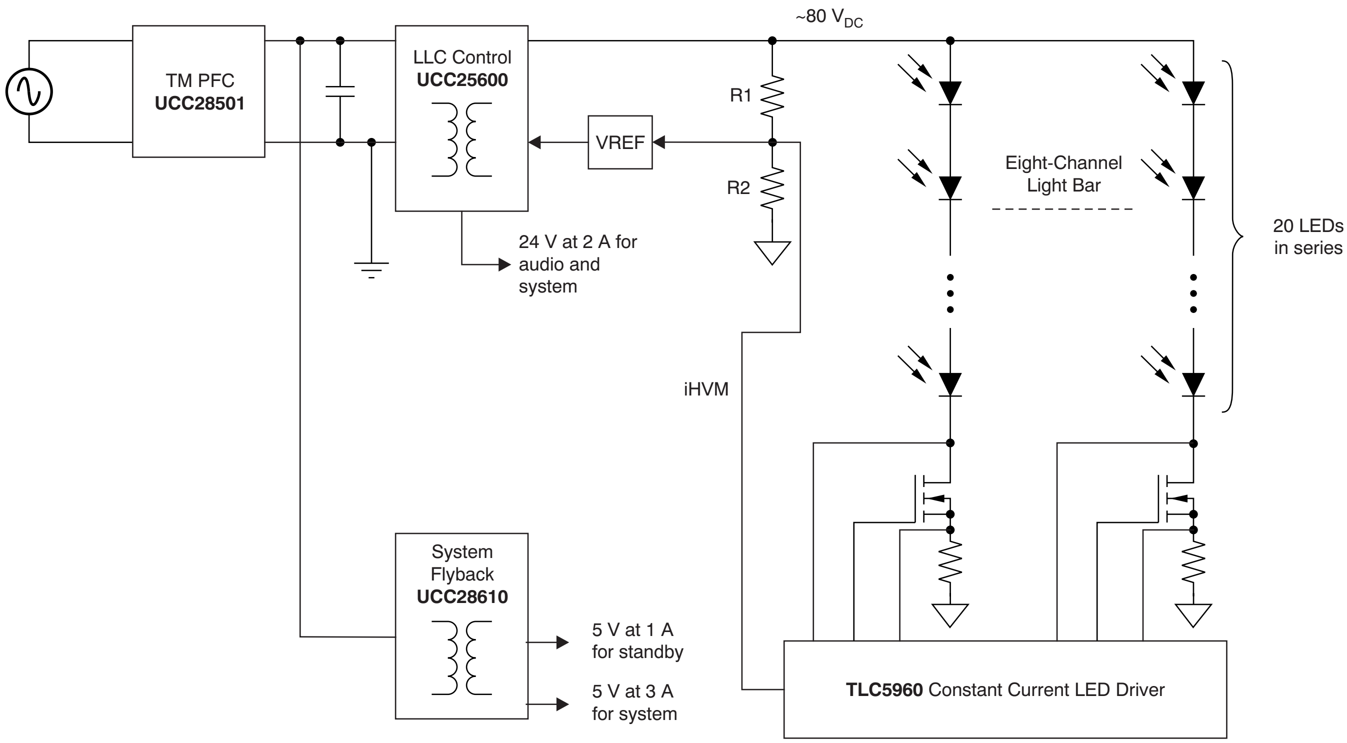


Figure 3. PMP4298A: Advanced Power Architecture for LED Backlight LCD TV

3 iHVM Basics

The LED forward voltage is subject to change depending on the forward current and the thermal resistivity of a given package. For instance, the temperature within an LCD TV starts at room temperature, and soon reaches approximately +70ºC. Assuming a typical LED component forward voltage reduction of ~5%, if the backlight total wattage is 100 W, then 5 W is turned directly into additional heat after the system powers on. Of course, this 5 W has an impact on the total power consumption of ~5%; however, a more significant impact is made on the thermal design. Imagine the additional 5 W heat inside a state-of-the-art, edge-lit TV with only 10-mm thickness. Even worse, this 5 W concentrates in some specific areas within the TV unit. To suppress the heat, one method is to turn on the cooling fan to lower the overall temperature. Or, a designer may be able to select an additional (larger) heatsink. However, keep in mind that 5 W is only assumed as a typical case; you should consider a higher value for your worst-case scenario in a real design.

The innovative iHVM design goal is to free engineers from this tiresome design task. If you want to minimize additional costs such as a larger (or additional) heatsink, you must manage the LED bias voltage according to the LED forward voltage change. The iHVM approach provides the perfect answer to that situation. iHVM detects the LED forward voltage and automatically optimizes the LED bias voltage to diminish the additional heat inside the system.

Equation 1 shows the iHVM-based LED voltage calculation. The dc-dc converter provides the LED bias voltage for all LED strings. The LED driver provides a fast linear switching capability as well as headroom voltage sense feedback. The output voltage of the dc-dc stage is calculated according to Equation 1.

$$V_{LED} = \frac{R1 + R2}{R2} V_{REF} + \frac{R1}{R3} (V_{REF} - V_{HVM}) \quad (1)$$

The left side of Equation 1 describes the typical dc-dc converter output voltage. The right side of the formula is the variable portion based on the iHVM additional feedback loop. The user can adjust the LED voltage with an additional resistor, R3, to fit it to the system-required V_{LED} bias voltage range within ±20%.

As Figure 4 shows, the total power system consists of two feedback loops: the primary loop and the iHVM-based secondary loop. In general, careful feedback design is required if two feedback loops are present on a single dc-dc converter to ensure stability. With the TLC5960, users do not need to compensate the secondary loop because this adjustment is handled by the fully-integrated digital iHVM control loop.

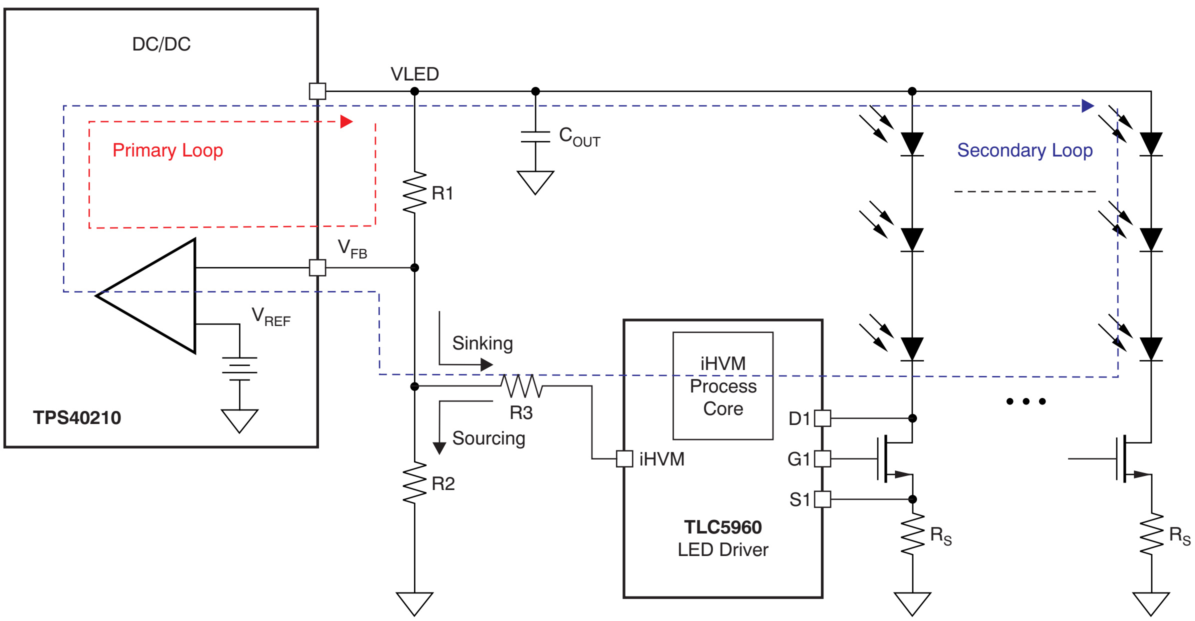


Figure 4. PMP4298: iHVM Feedback Loop Integration into DC-DC Primary Feedback Loop

Some of the benefits of the additional closed-loop feedback with iHVM include:

- Freedom from concern about any LED forward voltage change with a temperature or current change; the closed feedback loop always regulates the LED bias voltage to the appropriate level.
- Freedom from any additional feedback compensation design. The secondary closed-loop system has the advantage of automatic LED voltage adjustment; in general, however, the user also must apply careful feedback loop design to ensure stability. iHVM has the capability of intelligently adjusting the secondary loop response, and therefore the user does not need to be concerned about phase compensation design.
- Freedom from noise misdetection and retention when sampling the cathode node of LED strings for detecting any LED forward voltage change. iHVM is a fully-developed digital processing technique, and a noise guardband is already integrated for noise immunity in the extremely noisy environment within a TV unit.
- An easily-applied, advanced LED switching sequence. iHVM memorizes the V_{LED} bias voltage once optimized. This feature is not so easy to realize in a conventional analog feedback loop, and it is very beneficial for severe full-on, full-off light sequences that are intended to produce better brightness profiles, which are often required for modern 3-D TV designs.

  Design note: An iHVM-based system consists of an ideal secondary feedback loop. However, the transient response of the total system depends on the primary loop design of the dc-dc converter or the resonant converter stage.

4 Advanced iHVM Feedback Design: Direct Feedback to Isolated AC-DC Power Stage

iHVM is designed to be flexible and to work well with various configurations of primary feedback loops. iHVM can work with a non-isolated dc-dc power stage design (based on the PMP4298 and the TPS40210), and is also easily configurable with an isolated ac-dc power stage (using the PMP4298A and the UCC25600 directly). Figure 5 illustrates the PMP4298A application circuitry with an LLC resonant controller with feedback through isolation. Up to four feedback connections can be controlled from TLC5960 iHVM buffers; output levels are automatically adjusted through an internal iHVM mechanism to improve the linear LED driver efficiency.

Here, the LLC resonant converter output with variable frequency is regulated based on the shunt current through the TL431 voltage reference device. At the reference node of the TL431 (designated as the *FB* node), the voltage divider R1 and R2 is connected to define the primary feedback loop voltage. The iHVM mechanism feeds the LED forward voltage information back to the FB node through R_{HVM} and adjusts the LLC resonant converter output voltage according to the required LED forward voltage.

To sense the LED forward voltage in strings, the TLC5960 monitors the FET drain node voltage of each string first. Next, the TLC5960 processes the obtained information in an intelligent digital power logic block. Finally, the TLC5960 modulates the HVM pin output voltage, which adjusts the UCC25600 operating frequency to achieve an optimized output voltage, V_{LED}.

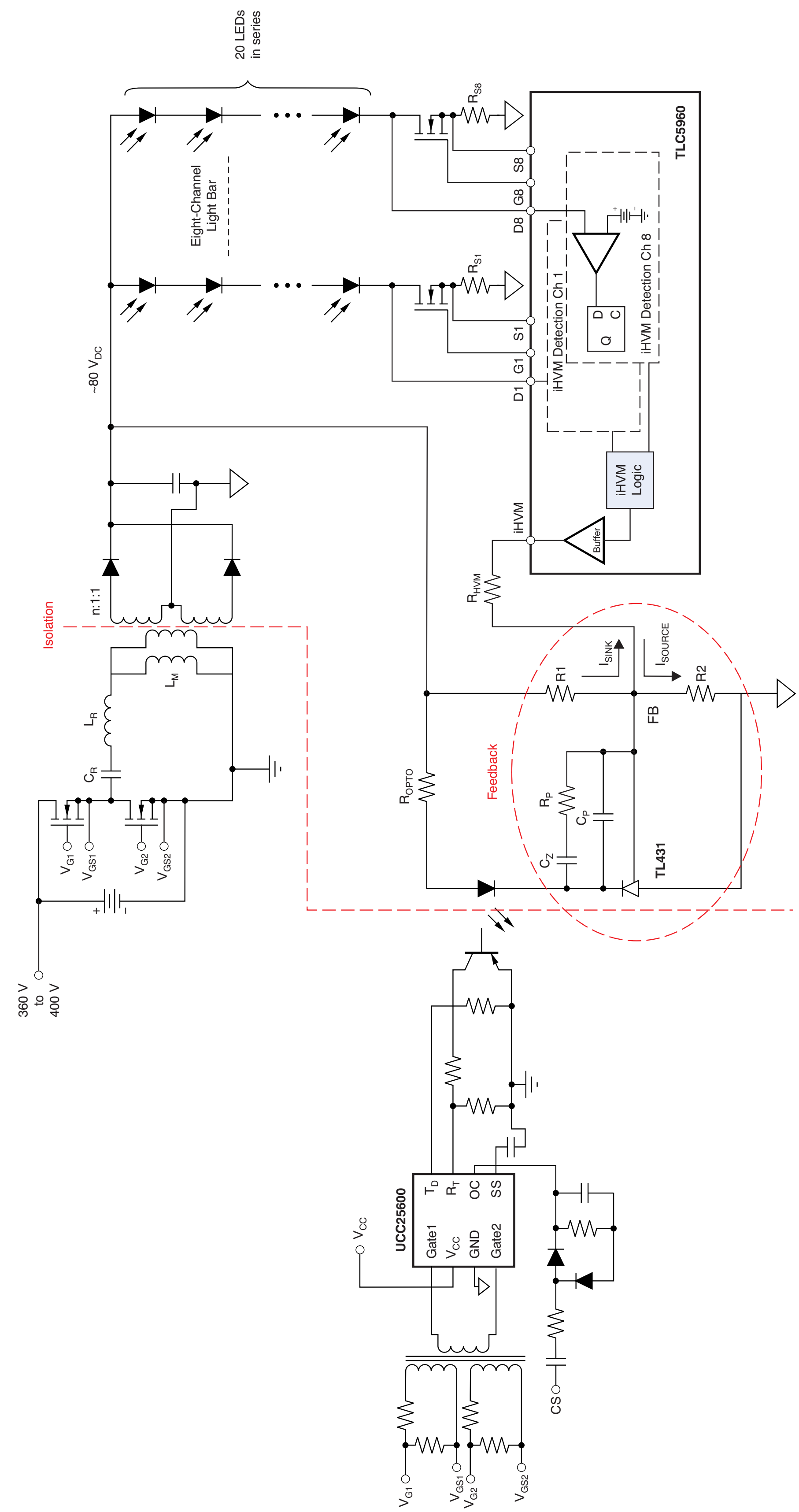


Figure 5. TLC5960 Application Circuit with LLC Resonant Converter

Figure 6 shows a block diagram of a total system that consists of an isolated ac-dc primary feedback loop and the iHVM secondary feedback loop. The primary feedback loop is the normal voltage feedback loop for the LLC resonant converter with voltage-controlled oscillation (VCO). The LLC resonant converter is based on a serial resonant converter (SRC) architecture. By using the transformer magnetizing inductance, zero-voltage switching can be achieved over a wide range of input voltages and loads. As a result of multiple resonances, zero-voltage switching can also be maintained when the switching frequency of the LLC controller is higher or lower than the resonant frequency. As the switching frequency is lowered, the voltage gain significantly increases. This characteristic allows the converter to maintain regulation when the input voltage falls low or the output current increases.

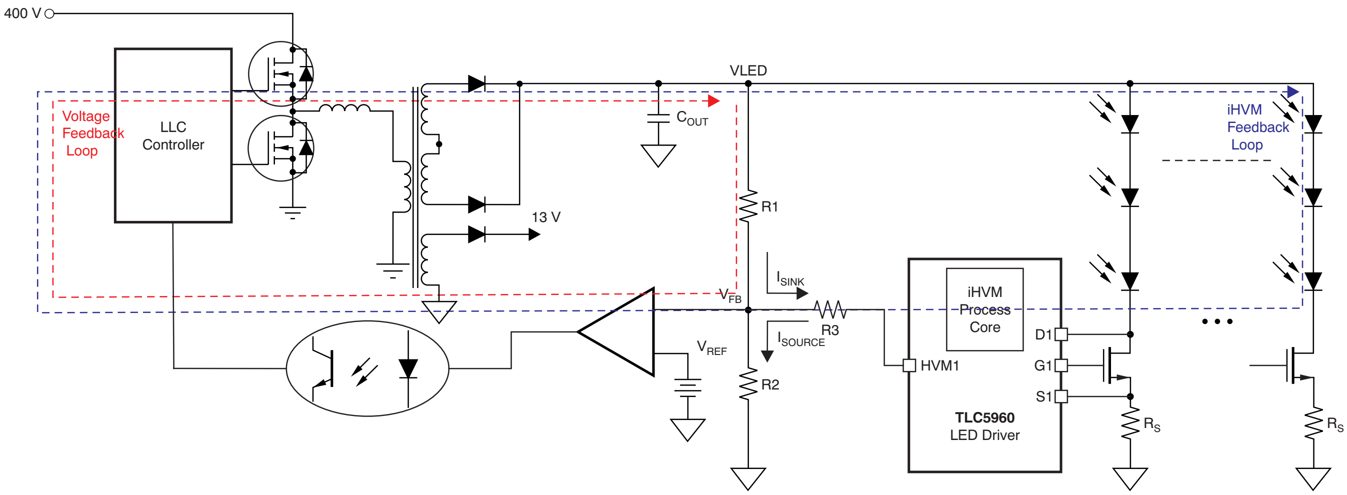


Figure 6. AC-DC Power-Stage Direct Feedback Loop Integrated with iHVM Secondary Feedback

The secondary feedback loop is intended to integrate the cathode node information of the LED string in order to optimize the power dissipation caused by the LED string voltage change as a result of the variance of the LED forward voltage. The V_{LED} output voltage equation is the same as for the iHVM with the non-isolated boost converter feedback loop (see Equation 1).

4.1 PMP4298A Start-Up Sequence of LLC Direct Feedback Through iHVM

Figure 7 illustrates the start-up sequence of this system. When the ac line powers on, the LLC resonant converter starts to work to output the initial V_{LED} voltage. After the user enables the TLC5960, the iHVM adjustment sequence kicks out the center value (0.7 V) of the HVM output control range (0.14 V to 1.25 V). Thus, the initial V_{LED} voltage is also set to start from the center value (here, 70 V) after the initial startup of the ac-dc power. Then, the TLC5960 begins to sense the LED string total forward voltage, and the HVM output starts to modulate. The UCC25600 then regulates the operating frequency with the voltage-controlled oscillation (VCO) to set the appropriate voltage of the V_{LED} that corresponds to the LED string total forward voltage.

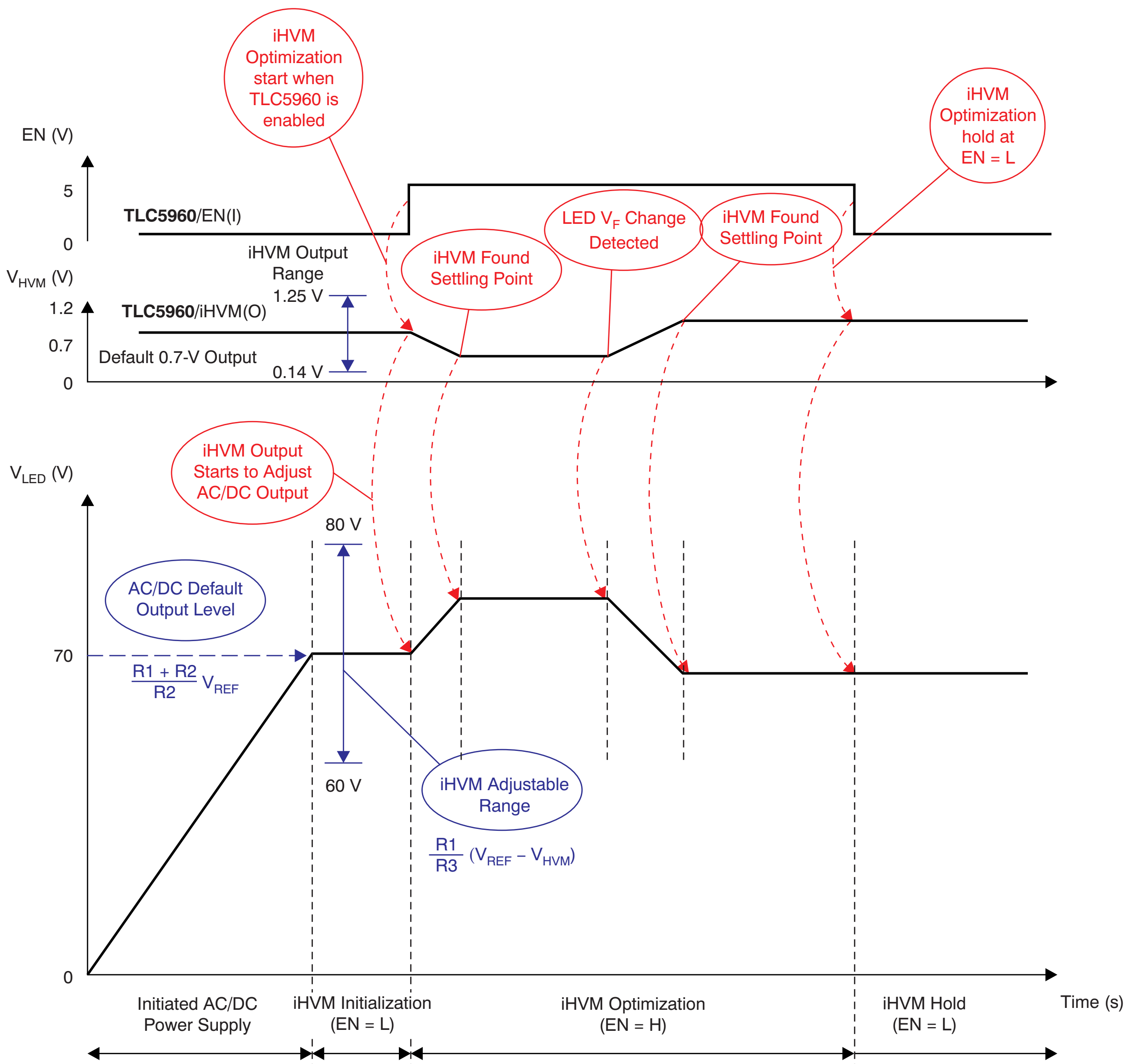


Figure 7. PMP4298A: AC-DC Power Stage Startup and iHVM Optimization Sequence

5 Protection Scheme

Protection is one of the key design parameters required to keep the total system safe in case of an abnormal situation. LED open detection and LED short detection are basic protection requirements in LED backlight systems. In the PMP4298/A, these LED-related protections are handled intelligently by the TLC5960. First, the TLC5960 monitors the Dn nodes (the cathode nodes of the LED strings) and determines whether an abnormal voltage range is detected or not. Then, the TLC5960 tries to resolve any abnormal situation by using the integrated iHVM feature. Finally, and only if the TLC5960 could not resolve the situation with iHVM, the TLC5960 recognizes an error and automatically shuts off the error string(s), separating them from normal working strings. The detection related diagram is shown in Figure 8.

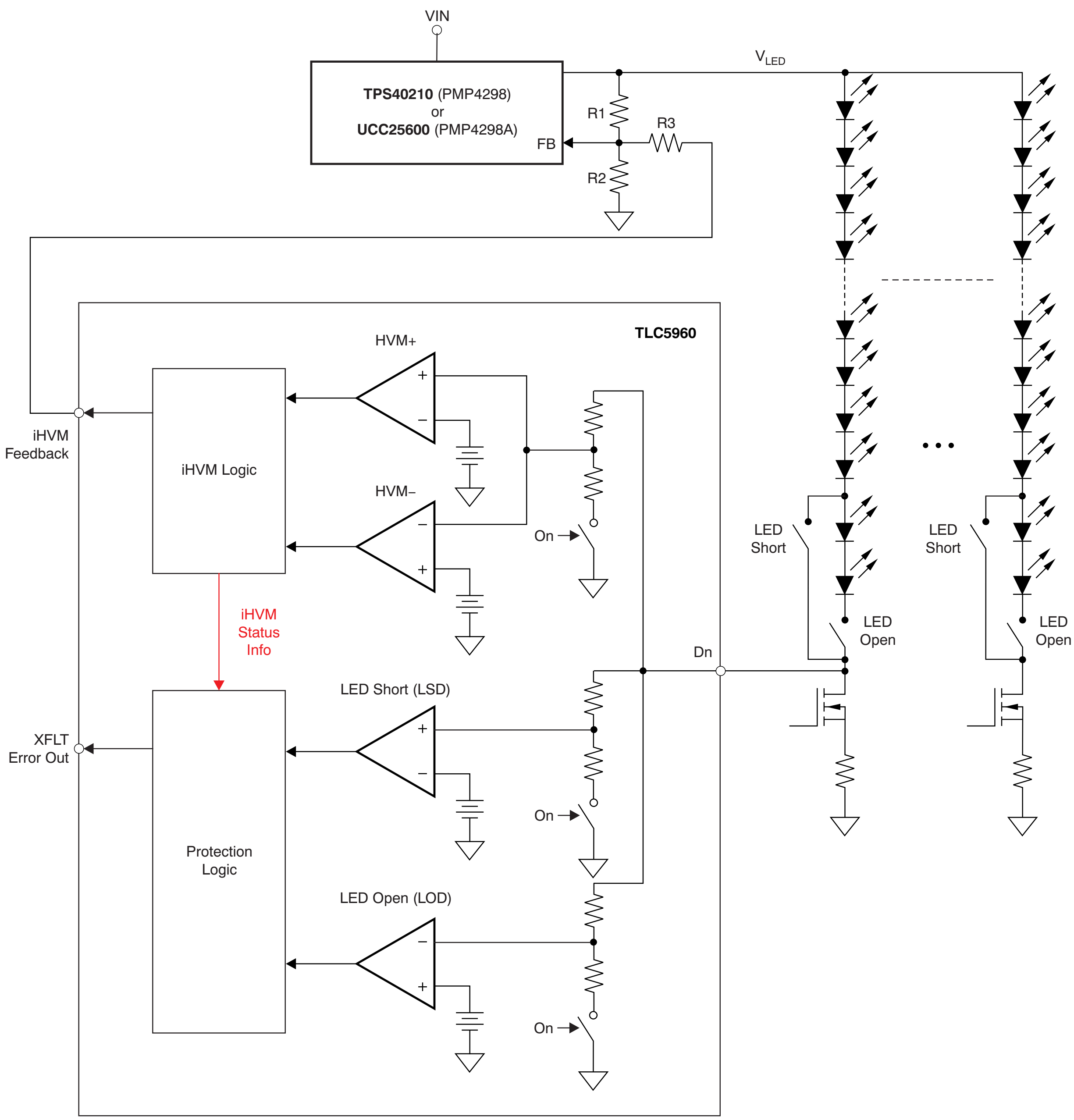


Figure 8. TLC5960 Total iHVM and Protection Scheme

For instance, an LED Open Detection (LOD) flag is triggered when the voltage Dn is lower than 0.8 V. When the TLC5960 recognizes this low voltage, the device tries to resolve the abnormal situation by driving to higher Dn voltages by lowering the HVM output voltage. And when the V_{LED} level reaches its maximum value, the TLC5960 recognizes an actual error status. Figure 9 shows this sequence. The LED short detection (LSD) sequence is also presented in Figure 10. In the case of an LED short, the TLC5960 also recognizes an abnormally higher voltage at Dx node. So, in this case, the iHVM mechanism tries to set V_{LED} at as low a voltage as possible. If this attempt fails, the TLC5960 recognizes this result as an error and initiates a corrective action: shut off the error string.

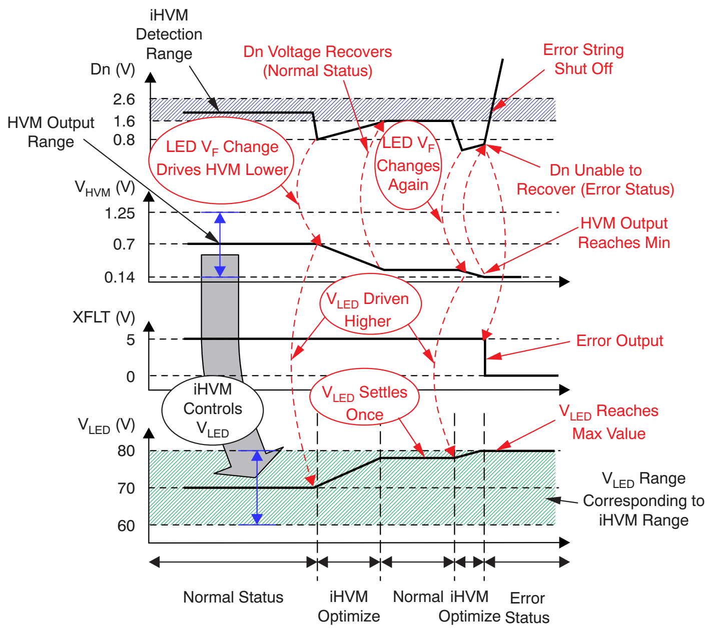


Figure 9. LED Open Detection and V_{LED} Optimization Through iHVM

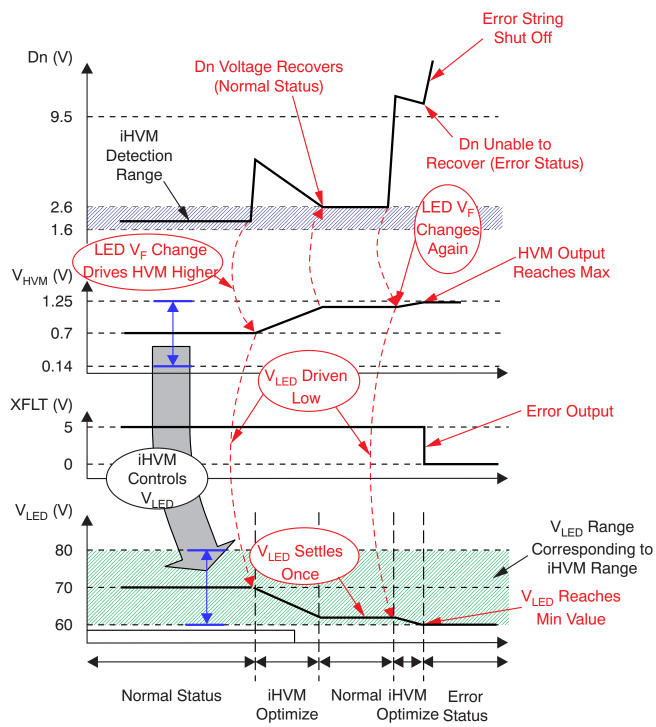


Figure 10. LED Short Detection and V_{LED} Optimization Through iHVM

These are the basic schemes used by the TLC5960 LED driver, which integrates both iHVM and protection features, to protect the LED backlight system intelligently. Table 2 summarizes the LED open and short conditions. This table also describes the Dn node recognition internal circuitry and how the iHVM information is integrated into the protection recognition routine.

Table 2. LED Open and Short Protection Conditions

LED Error Status	Dn Error Detection Voltage	iHVM Status to Trigger Error Detection
LED Open	Dn < 0.8 V	V_{LED} reaches the maximum value (HVM = 0.14 V)
LED Short	Dn > 19.2 V (default)	V_{LED} reaches the minimum value (HVM = 1.25 V)

6 Experimental Results

In order to verify the proposed LED backlight TV power supply design using intelligent headroom voltage control, two reference design demonstration fixtures are constructed using the PMP4298 and PMP4298A. Typical specifications of the reference design include:

- Input: 150-W universal ac input power supply (85 V_{AC} to 264 V_{AC}, at 47 Hz to 63 Hz)
- Greater than 85% efficiency from ac to LED backlight at 220 V_{AC} input
- Power output:
  - LED strings: Eight channels x 80 V with 20 120-mA LEDs per string
  - Audio and system: 24 V at 2 A
  - System: 5 V at 3 A
  - Standby power: 5 V at 1 A
- Minimum 20-ms hold-up time when the input line is shut off
- Input standby power Less than 500 mW with 5-V/30-mA output (onboard switch can trigger standby mode)
- Printed circuit board (PCB) specifications:
  - Single layer board
  - X-Y dimensions (max):10 inches x 10 inches (25.40 cm x 25.40 cm)
  - Height (max): .394 inches (10 mm)—not including PCB thickness
- Dimming range: 1% to 100% (250-Hz dimming frequency)
- LED current matching specification: Less than 3% for full dimming range
- Flyback stage output regulation tolerance: Less than ±5% over the load range
- LED protection (short, open, overcurrent, undercurrent, undervoltage, etc.)
- OCP and OVP protection for the Flyback stage
- In Standby mode, system disables PFC and LLC stages to reduce standby power
- TLC5960 headroom voltage mode (iHVM™) to control the UCC25600 LLC output and optimize efficiency
- Meets IEC 61000-3-2 for total harmonic distortion
- Meets EN55022 Class B EMI requirements
- Operating temperature range: 0ºC to +50ºC; storage temperature range: –20ºC to +80ºC

Figure 11 shows the demonstration fixture PMP4298A configured with an eight-channel LED light bar in the test setup.

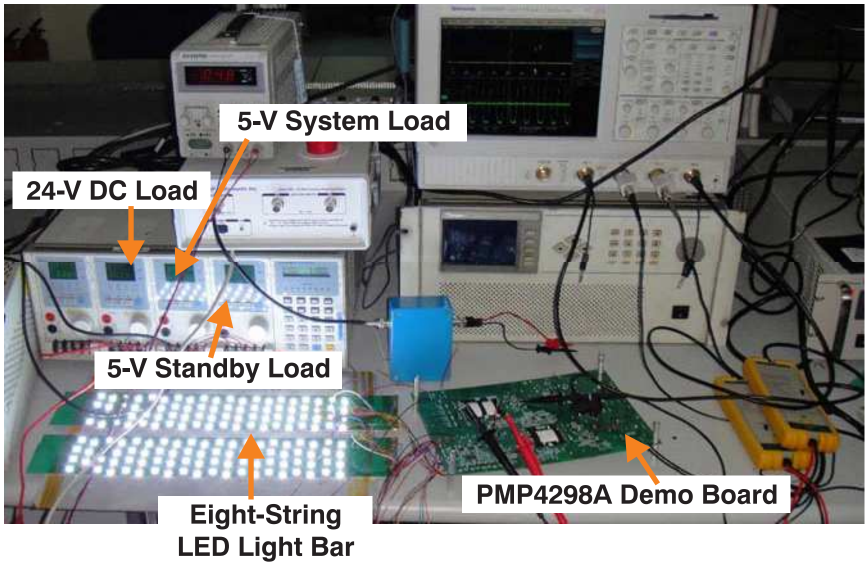


Figure 11. PMP4298A Demonstration Fixture Test Setup

Figure 12 presents a total efficiency comparison with an input voltage range from 90 V_{AC} to 264 V_{AC} at a full load for both the PMP4298 and PMP4298A designs. Overall, the PMP4298 shows good efficiency (85%). Furthermore, by omitting the front-end boost dc-dc stage, the PMP4298A shows an 88% peak, or 2% superior performance than the PMP4298 in efficiency with a lower cost structure. The 3% power-loss savings in a total 150-W design is equivalent to a 4.5-W saving for thermal components. For additional improvements, the user must also consider appropriate transformer and MOSFET selection, because most of the loss comes from the transformer core loss and the FET switching loss. Figure 13 shows the power factor at a full load for the PMP4298A.

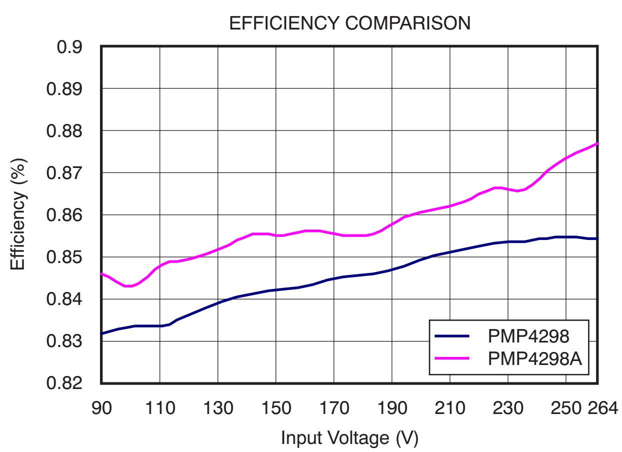


Figure 12. Total Efficiency Comparison at Full Load on V_{LED}, 24 V and 5 V

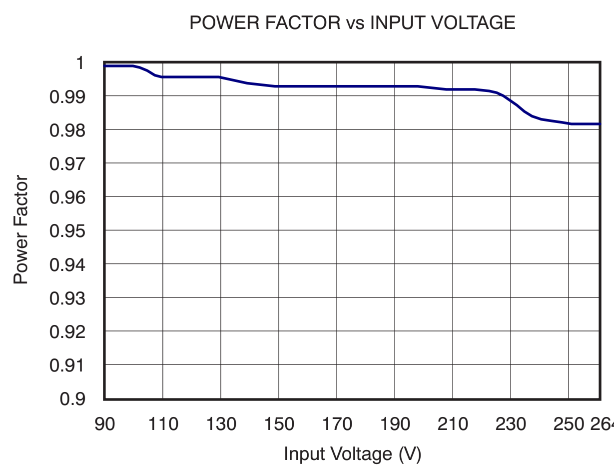
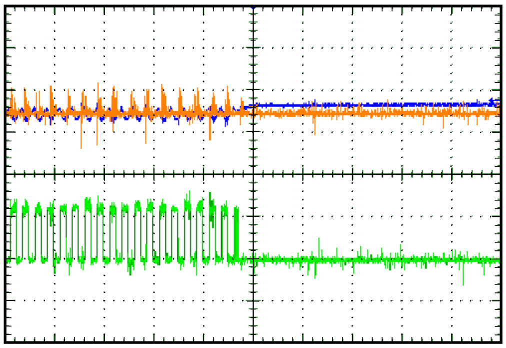
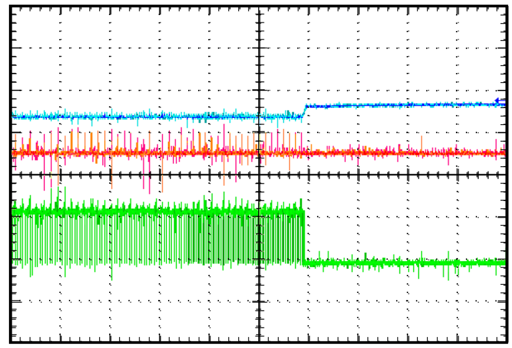


Figure 13. Power Factor at Full Load for PMP4298A

Figure 14 shows the waveforms from the LED light bar ON to OFF at 50% and 90% PWM dimming for V_{O_LED} (blue line), iHVM (red line), and the output LED current (green line). After V_{LED} turns ON, by the heat of the LED itself, the LED forward voltage is lower; iHVM detects that change and controls V_{LED} to be a little lower, cycle by cycle, to achieve maximum total efficiency in power across the board.



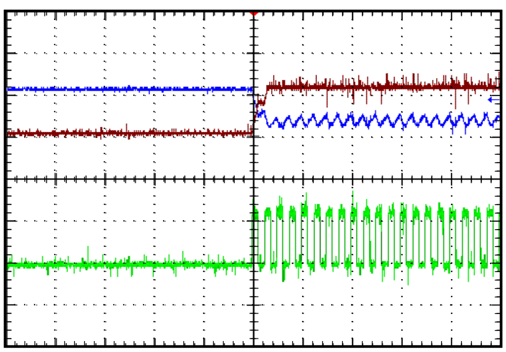
(a) 50% PWM Dimming



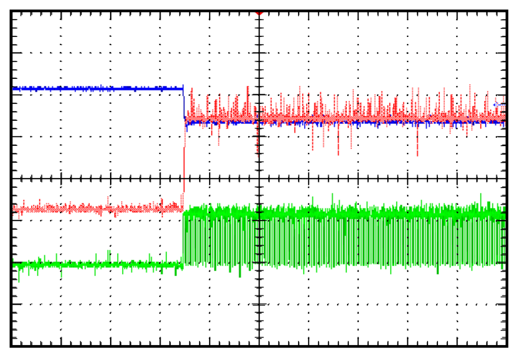
(b) 90% PWM Dimming

Figure 14. Output Headroom Voltage Waveforms for PMP4298A: LED ON to OFF

Figure 15 shows the waveforms from the LED light bar OFF to ON at 50% and 90% PWM dimming for V_{O_LED} (blue line), iHVM (red line), and the output LED current (green line).



(a) 50% PWM Dimming



(b) 90% PWM Dimming

Figure 15. Output Headroom Voltage Waveforms for PMP4298A: LED OFF to ON

See Appendix A for schematics for the PMP4298 and PMP4298A.

7 Conclusion

This application note shows two reference designs, which are both applicable to various LED backlight applications. One of the key features of these recommended designs is the V_{LED} control methodology (iHVM) that reduces power dissipation, additional costs, and overall design effort. The iHVM was originally designed to work well not only for normal dc-dc converter stages (PMP4298), but also with slower response ac-dc resonant converter stages (PMP4298A).

Another key feature is system safety. By combining the V_{LED} control mechanism and the integrated protection mechanisms, the total system is robust even in abnormal situations. Experimental results confirmed 88% peak efficiency including total ac-dc TV power outputs while maintaining a 98% power factor for a wide input range from 85 V_{AC} to 264 V_{AC}.

8 References

Unless otherwise noted, these documents are available for download through the Texas Instruments website (www.ti.com).

- TLC5960 8-channel LED driver controller with integrated intelligent thermal controller. Product data sheet. Literature number SBVS147.
- UCC28610 Green-mode flyback controller. Product data sheet. Literature number SLUS888D.
- UCC25600 8-pin high-performance resonant mode controller. Product data sheet. Literature number SLUS846A.
- UCC28051 PFC controller for low to medium power applications requiring compliance with IEC 1000-3-2. Product data sheet. Literature number SLUS515F.

Appendix A Schematics

Schematics for the PMP4298 and PMP4298A are given in Figure 16 to Figure 21.

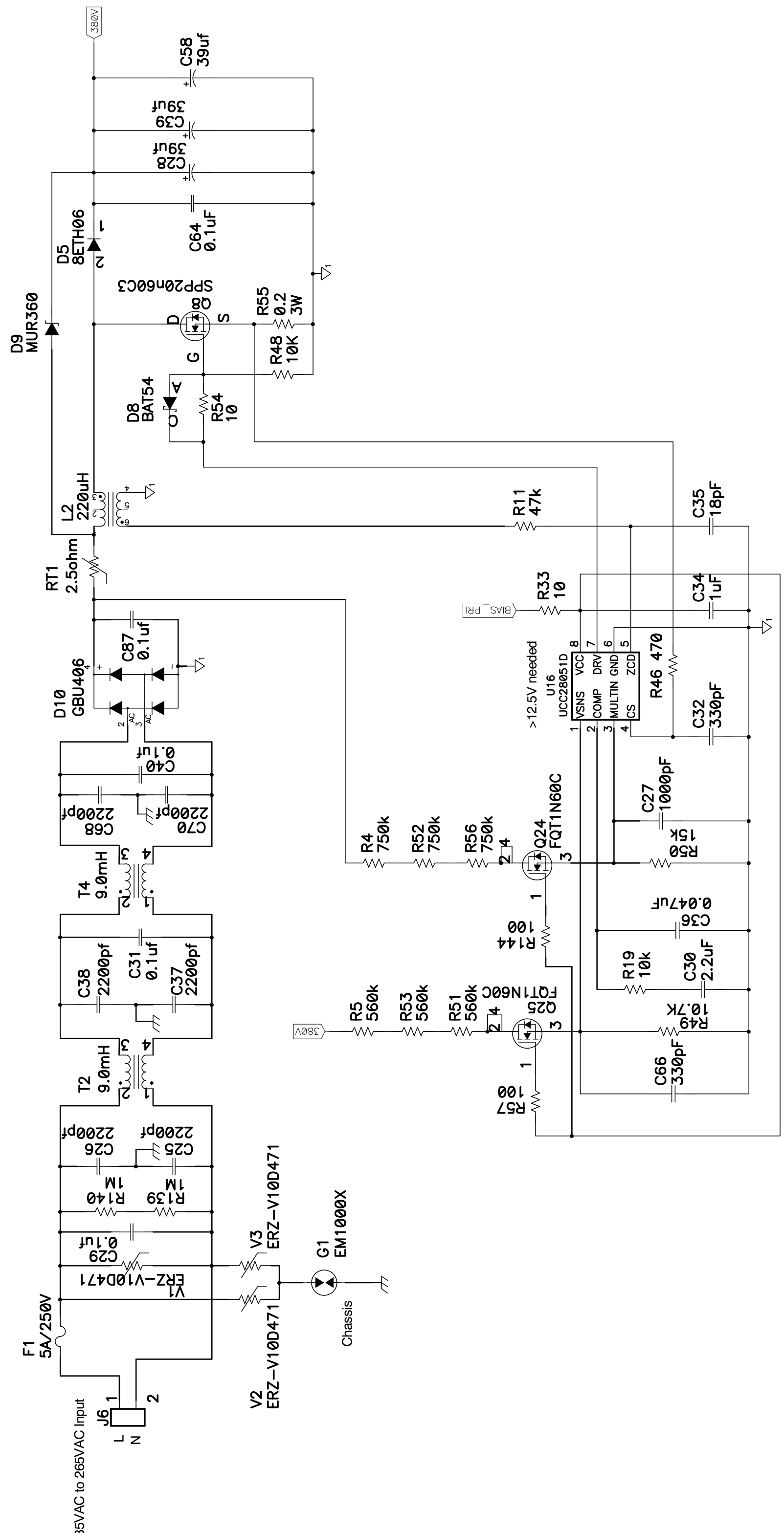


Figure 16. PFC Stage Schematic for PMP4298 and PMP4298A

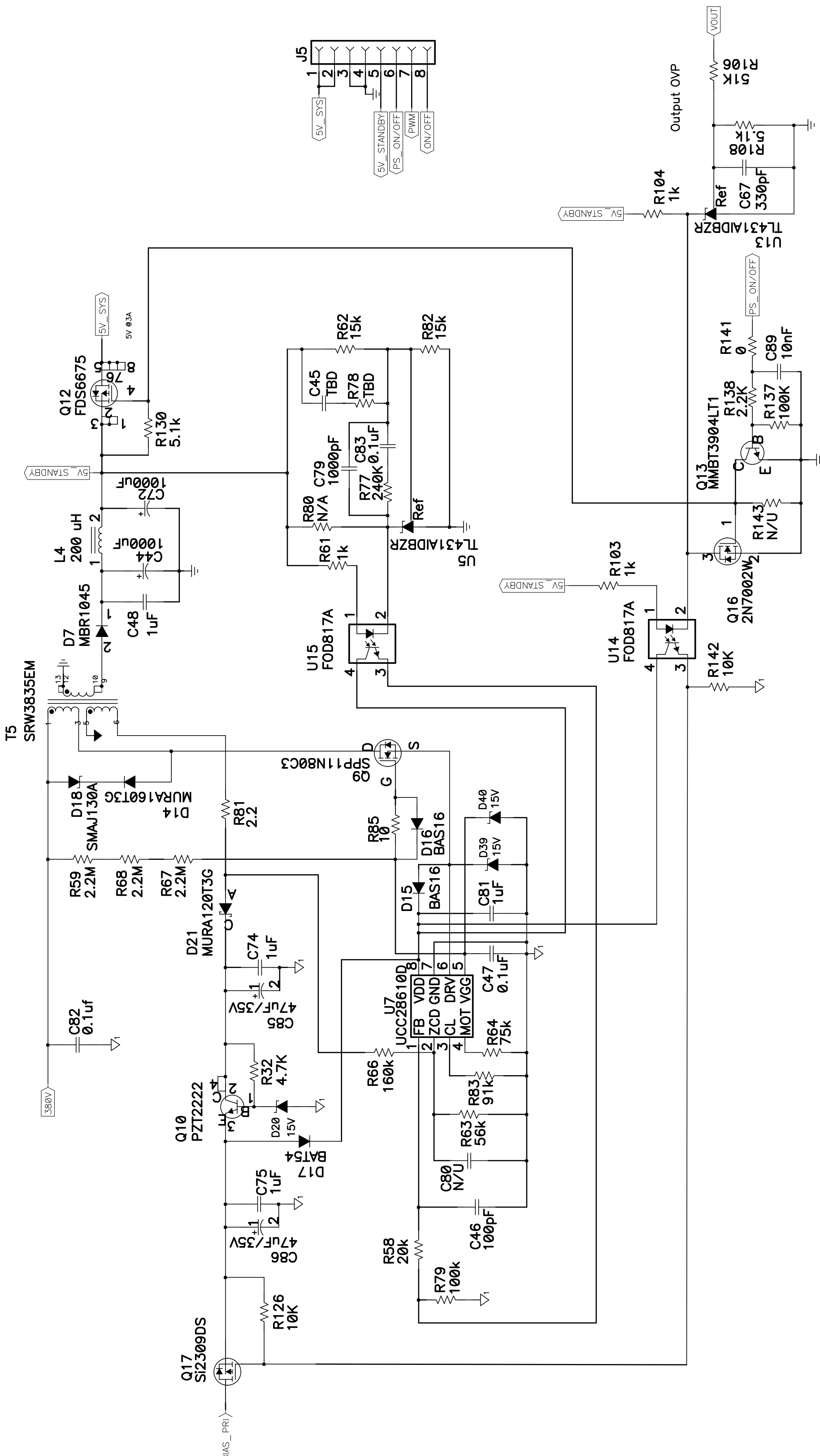


Figure 17. Auxiliary Flyback Converter Stage Schematic for PMP4298 and PMP4298A

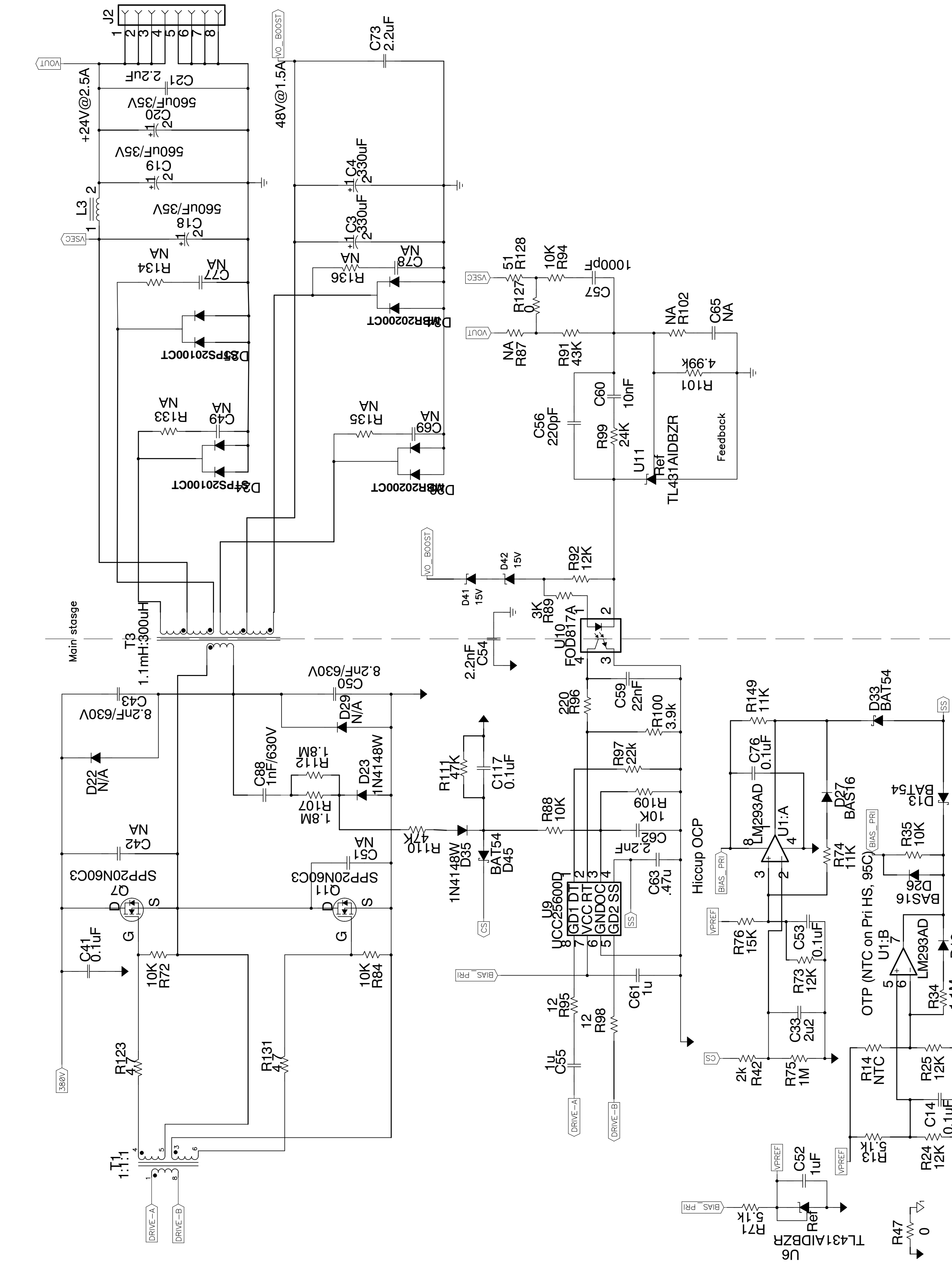


Figure 18. LLC Converter Stage Schematic for PMP4298

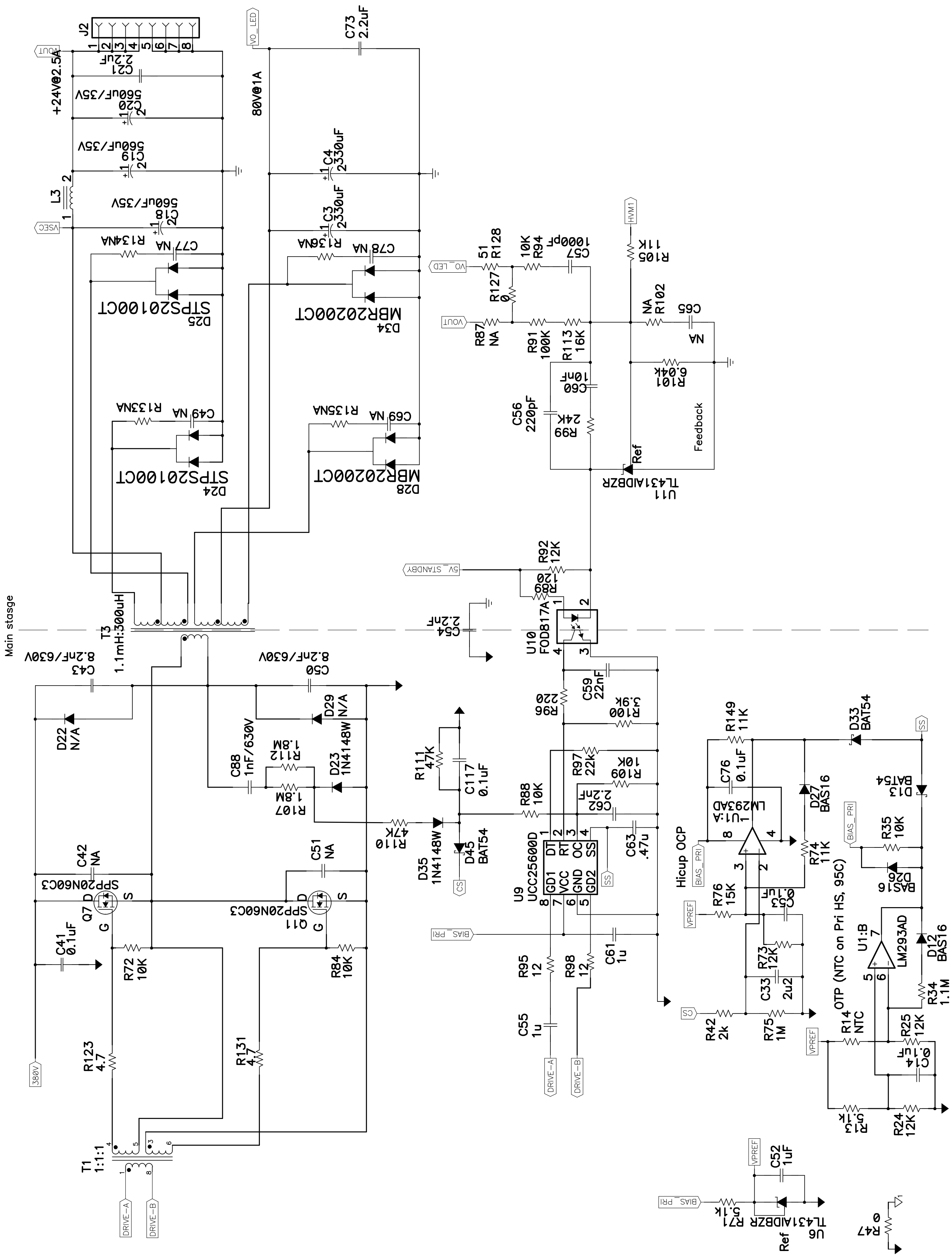


Figure 19. LLC Converter Stage Schematic for PMP4298A

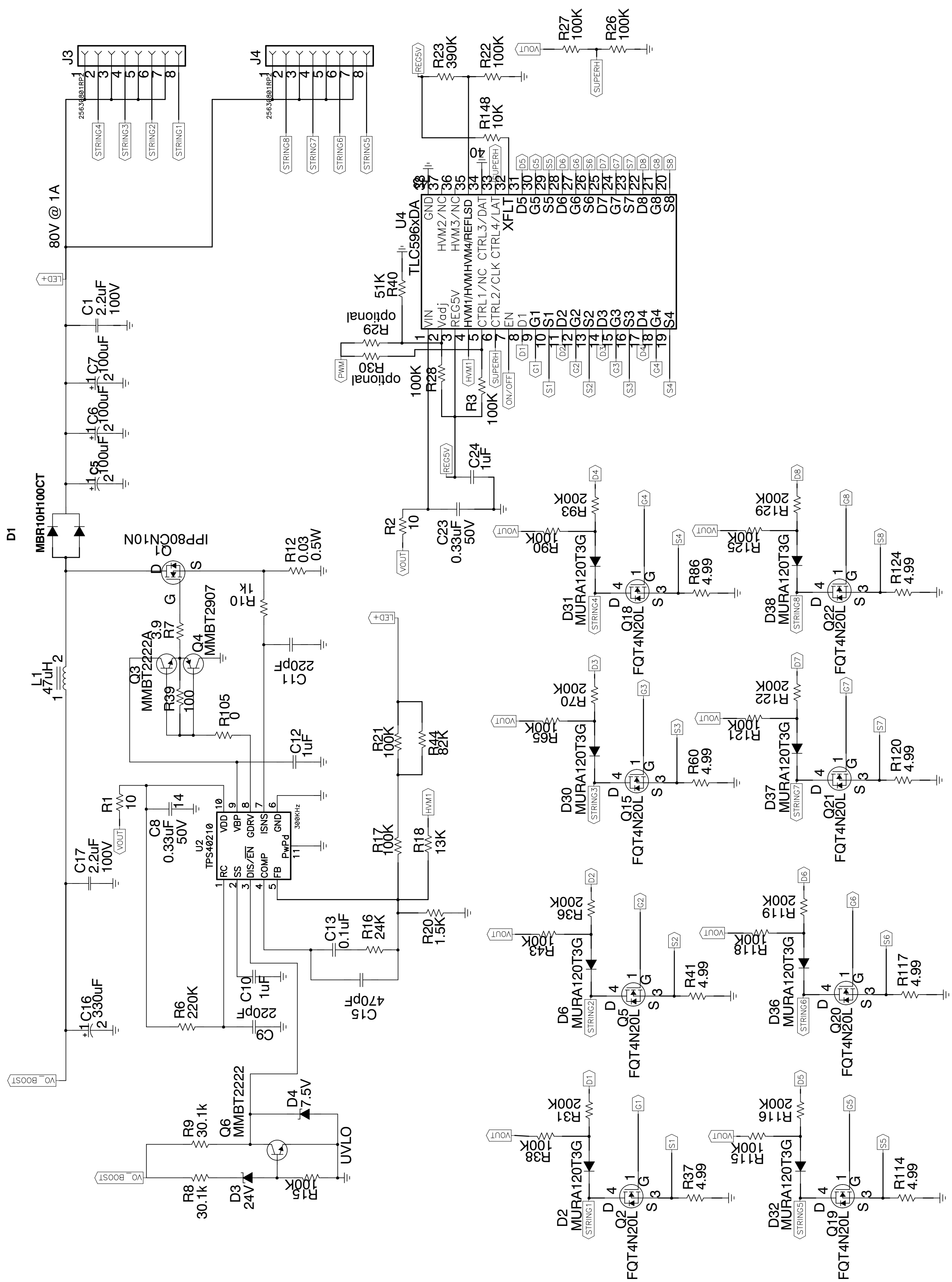


Figure 20. TLC5960 LED Driver Stage Schematic for PMP4298

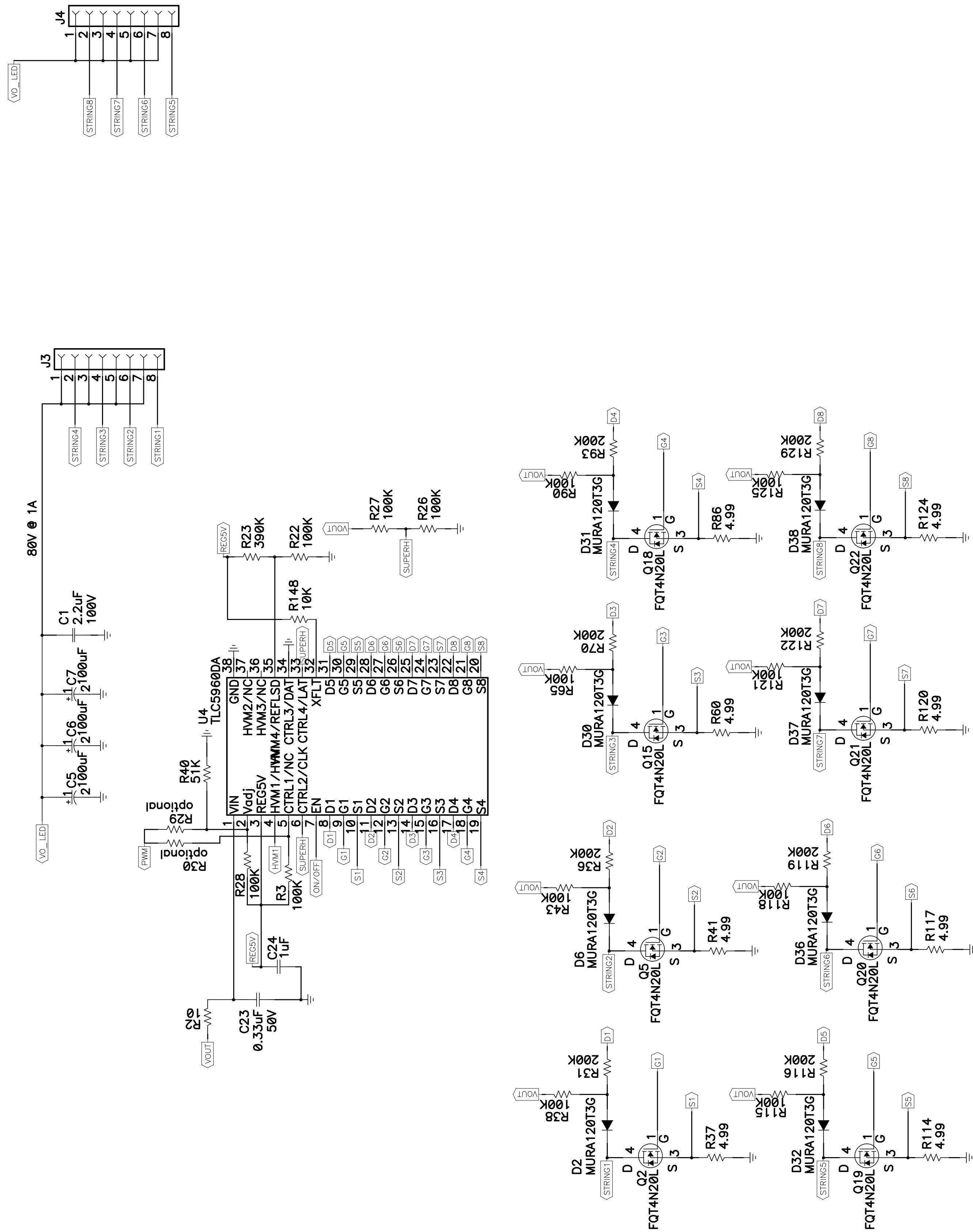


Figure 21. TLC5960 LED Driver Stage Schematic for PMP4298A

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