DLP® Pico LED Driver Design Guide and LM3434

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ABSTRACT

This application note presents the operation principles for PWM LED driver control interface on DLP® Pico ASICs along with the driver performance assessment on DLP® projection display. Section 4 of the application note introduces LM3434 as the discrete LED driver on Pico products and includes the schematic, O-scope performance measurement, and design guidelines for mainstream LED products.

The application notes apply to DLPC6401 and DLPC2607 as long as the PWM driver controls the interface. The same LM3434 schematic can be adopted with the appropriate changes per LED Vf and If driving specification.

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1 Introduction

The single-DMD-chip DLP® LED projector is known as using color-sequential method to produce colors that turn Red, Green, or Blue LEDs On at a time within the whole frame time. In a pure LED illumination system, Red, Green, and Blue LEDs must be used with dichroic mirrors with the appropriate optical layout and form the same incident light cone to DMD as shown in Figure 1. Particular DLP® ASICs support color overlap to generate Yellow, Cyan, Magenta, or White by turning On at least two LEDs simultaneously (that is, Red + Green = Yellow). Figure 2 and Figure 3 show two example timing charts of RGB only and Overlap control scheme; logic high represents enabling the particular corresponding LED.

The LED driver plays a critical role driving LEDs in a DLP® projection system by taking the control signals from the DLP® ASIC. An unqualified LED driver was typically determined as the source of many errors in picture-quality related problems, and most of the problems cannot be mitigated by software optimization, but the hardware modification is mandatory. Therefore, it is highly encouraged to perform detail driver evaluations in the beginning design phase. Section 2 and Section 3 share the work principles of driver control interface and the criteria in evaluating the driver performance.

Section 4 and Section 5 introduce a qualified LED driver by using the TI LM3434 which is recommended in discrete LED drivers for less than 25-A LED products.

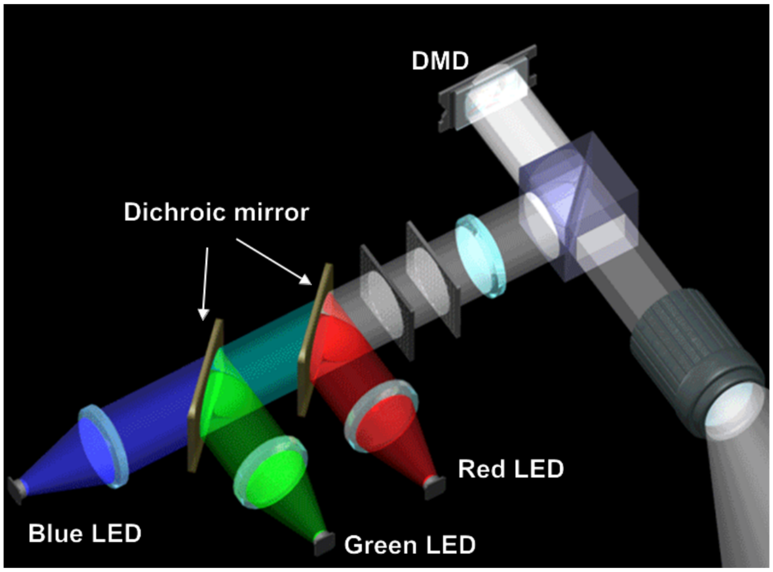


Figure 1. Optical Layout of DLP® LED Projector

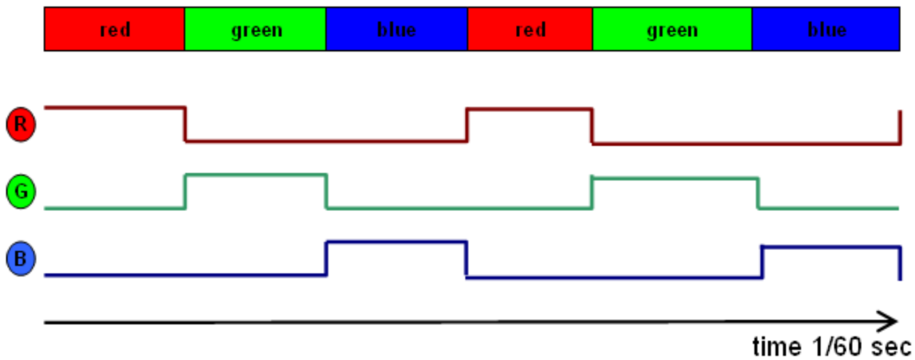


Figure 2. RGB-Only LED Control Scheme in 60-Hz Video

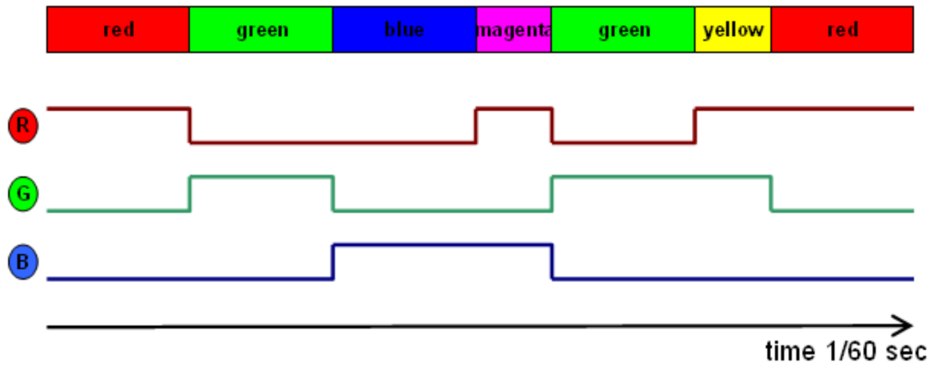


Figure 3. Yellow and Magenta Overlap Control Scheme

2 DLP® ASIC and LED Driver Interface

Typically, a DLP® control ASIC has three PWM output pins which control the duty cycle to drive R-, G-, and B-LED current level, and three LED enable pins that indicate the duration to turn On the corresponding LED. LED drivers should follow LED enable and LED PWM to control LED. Figure 4 shows the LED driver interface on the DLPC6401 and DLPC2607 reference schematic.

In general, the PWM frequency output pins run at 10 to 30 kHz, and add the R-C filter to integrate the digital PWM duty cycle into DC level to indicate the level of LED current on LED drivers, since most LED drivers take DC level to control LED current. See Figure 5 as an example.

LED enable is the signal that controls LED On and Off time. An example of 4-color cycle-per-frame sequence, the LED enable signal drives LED at 4 times per frame, and the waveform of each LED enable signal should repeat every frame. For some specific ASICs with overlap sequence support, the operation mode may include at least two LED enable signals that turn On simultaneously at part of each frame time, as shown in Figure 3.

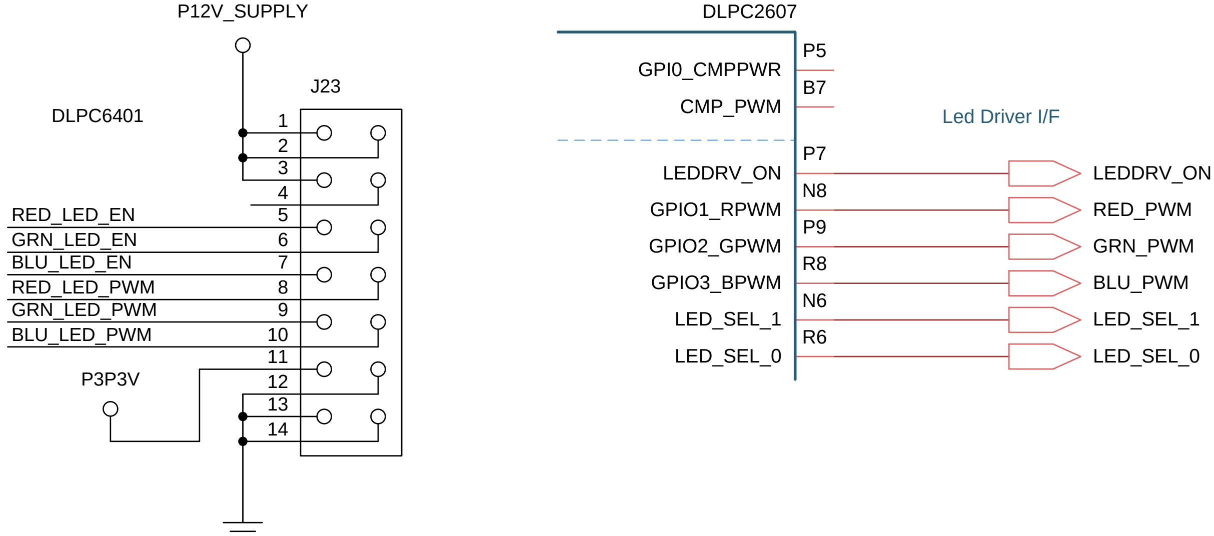
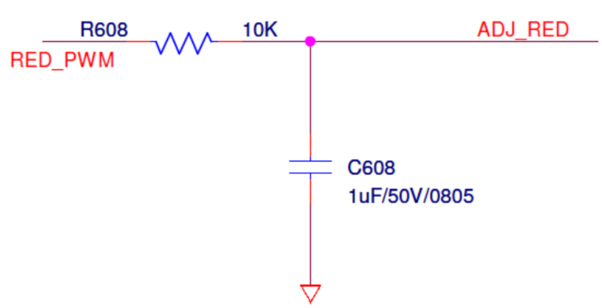


Figure 4. DLPC6401 and DLPC2607 LED Driver Interface



(The resistor and capacitor value is the subject depends on design)

Figure 5. R-C Filter to Convert Digital PWM into DC Level

3 LED Driver Performance Evaluation

Ideally, LED current should exactly follow LED enable signals without any waveform deformation and response delay. Any enable delay or current waveform deformation are the source of error inducing an image artifact such as gray ramp non-linearity or skin tone contour, and so forth. However, it is not easy to have an ideal LED driver in the system. In practical application, most of the LED drivers in the present market have different levels of deformation and response delay issues and the turns out to be the consideration of cost versus performance. The final image result is usually judged by human eye or user-defined image quality specification to qualify the LED driver. Section 3.1 through Section 3.4 describe known LED driver performance issues which result in real image quality problems. LED driver designers must seriously consider each issue.

3.1 LED Driver Response Delay

In general, two types of LED driver response delays exist; ideally both delay times should be zero. Fortunately, LED response delay is the only driver performance issue that can be compensated by software adjustment. DLP® Composer has the interface to make up the delay problem.

Note in Figure 6:

“A” represents Enable delay: the time from LED enable to actual LED On.

“B” represents Disable Delay: the time from LED enable Off to actual LED begin Off.

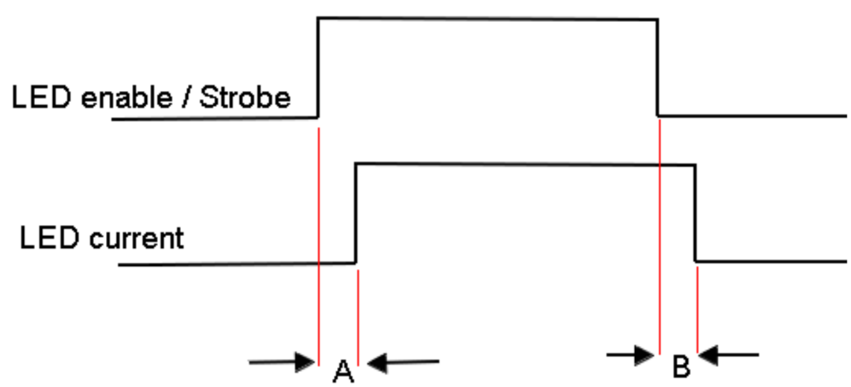


Figure 6. LED Driver Response Delay

3.2 LED Current Overshoot and Undershoot

It is assumed the LED current is completely flat all the time while the DMD mirror flips. As long as the LED current is not stable during DMD operation and shows as overshoot or undershoot, as shown in Figure 7, the LED current is the source of error for image quality problems.

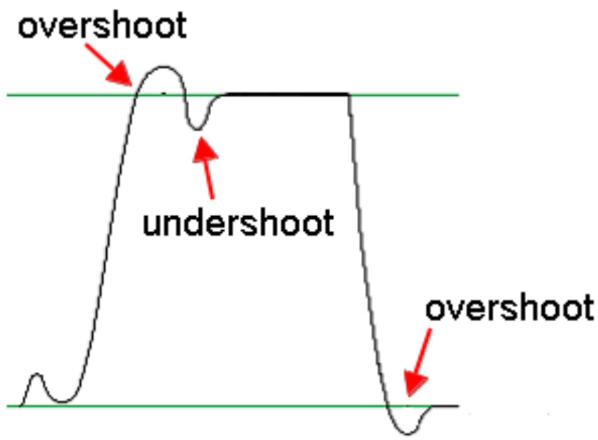


Figure 7. LED Current Overshoot and Undershoot

3.3 LED Current Rising and Falling Time

Typically rising time and falling time is the unit defining the duration when the LED current is from 10% to 90% or 90% to 10%. Shorter times result in better image quality.

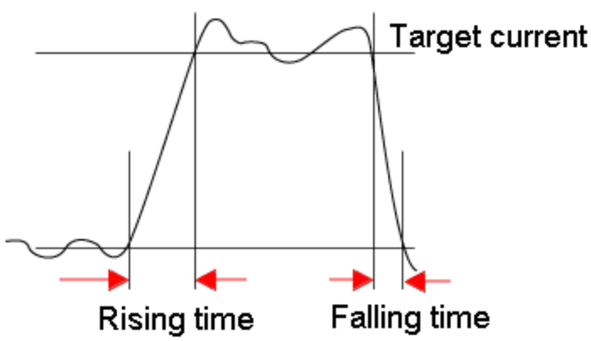


Figure 8. LED Current Rising and Falling Time

3.4 LED Current Ripple

The current ripple shown in Figure 9, illustrates how the current cannot remain stable while reaching the plateau. In the LED driver design phase, either reduce the ripple amplitude or increase the ripple frequency to avoid impacting the image quality.

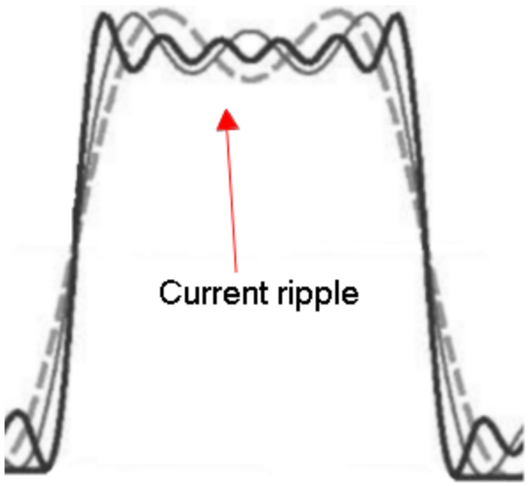


Figure 9. LED Current Ripple

4 LM3434 on DLP® Pico Products

4.1 Introduction

The LM3434 is an adaptive constant on-time DC/DC buck constant current controller designed to drive high-brightness LEDs (HB LED) at high forward currents. It is a true current source providing a constant current with constant ripple current, regardless of the LED forward voltage drop.

This circuit changes the output configuration from common anodes to common cathodes and the board can accept an input voltage from 9 V to 30 V making it more convenient for users to adopt a traditional power supply.

4.2 LM3434 Board Description

The evaluation board is designed to provide a constant current in the range of 4 A to 25 A. This application requires two positive inputs for operation; one positive voltage with respect to VIN is required for bias and control circuitry, and another positive voltage with respect to GND is required for the main power input. The evaluation board only requires one input voltage from 9 V to 30 V with respect to GND for main power input. The bias voltage with respect to V_{IN} is supplied by the LM5002 circuit. The LM5002 circuit also provides a UVLO function to remove the possibility of the LM3434 from drawing high currents at low input voltages during start up. The DLP® control ASIC has three PWM output pins which control the duty cycle to drive R-, G-, and B-LED current levels, this signal filters to DC levels from 0.3 V to 1.5 V and feeds into the ADJ pin to linearly control the R-, G-, and B-LED current, and three LED enable pins that feed into the DIM pin and indicate the duration to PWM to turn the R-, G-, and B-LED current On and Off .

4.3 Setting the LED Current

The LM3434 uses average current mode control to regulate the current delivered to the LED. An external current sense resistor (R_{SENSE}) in series with the LED is used to convert I_{LED} into a voltage that is sensed by the LM3434 as the CSP and CSN pins. CSP and CSN are the inputs to an error amplifier with a programmed input offset voltage (V_{SENSE}). V_{SENSE} is use to regulate I_{LED} using the following equation:

$$I_{LED} = V_{SENSE} / R_{SENSE}$$

4.3.1 Fixed LED Current

The ADJ pin sets VSENSE. Tie ADJ to VIN to use a fixed 60 mV internal reference for VSENSE. Select RSENSE to fix the LED current based on the following equation:

$$R_{SENSE} = 60 \text{ mV} / Iled$$

4.3.2 Adjustable LED Current

When tied to an external voltage the ADJ pin sets V_{SENSE}, based on the following equation:

$$V_{SENSE} = (V_{ADJ} – V_{CGND}) / 16.6$$

For this application, ADJ is tied to DLP's PWM frequency output pins through a level circuit and tied to the LM3434 ADJ pins. PWM frequency runs at 10 to 30 kHz, and adds the R-C filter to integrate the digital PWM duty cycle into DC level from 0.3 V to 1.5 V to indicate the level of LED current on the LED driver.

4.4 PWM Dimming for R, G and B Strobe

The DIM pin of the LM3434 is designed so that it may be controlled using a 1.6 V or higher logic signal. The PWM frequency easily accommodates more than 40-kHz dimming and can be much faster if needed. If the PWM DIM pin is not used, tie it to CGND or leave it open. The DIM pin is tied to CGND internally through a 100-kΩ pull-down resistor.

For this application, DLP's EN output pins through level shift circuit and tied to LM3434 DIM pin to control LED On and Off time.

5 LM3434 Schematic Change for Various Vf If LEDs

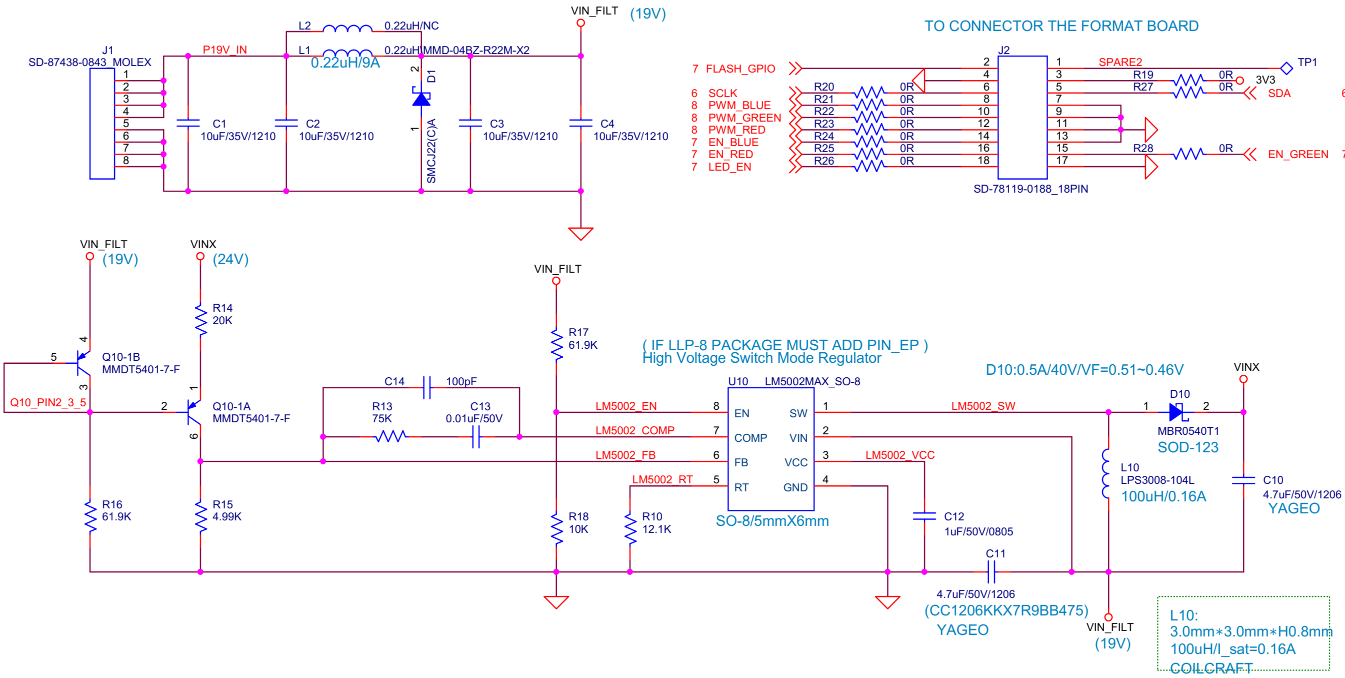


Figure 10. LM5002 Evaluation Board Schematic

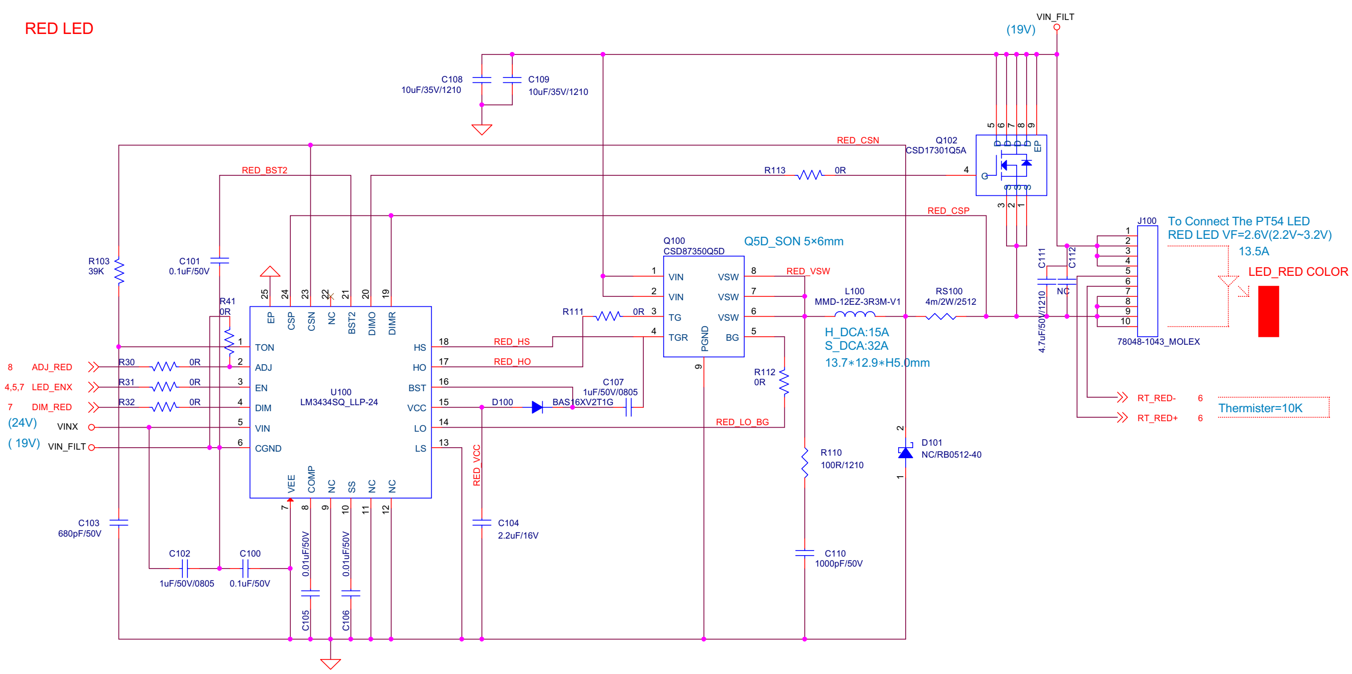


Figure 11. LM3434 Red LED Driver Schematic

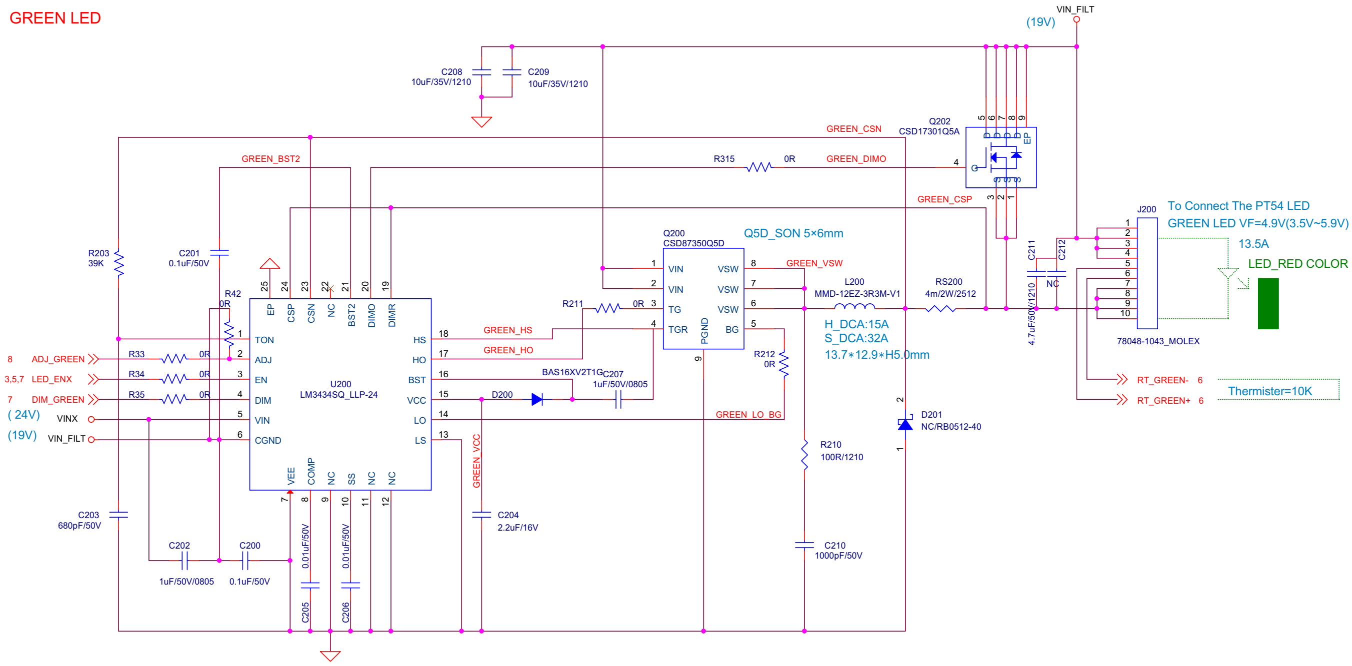


Figure 12. LM3434 Green LED Driver Schematic

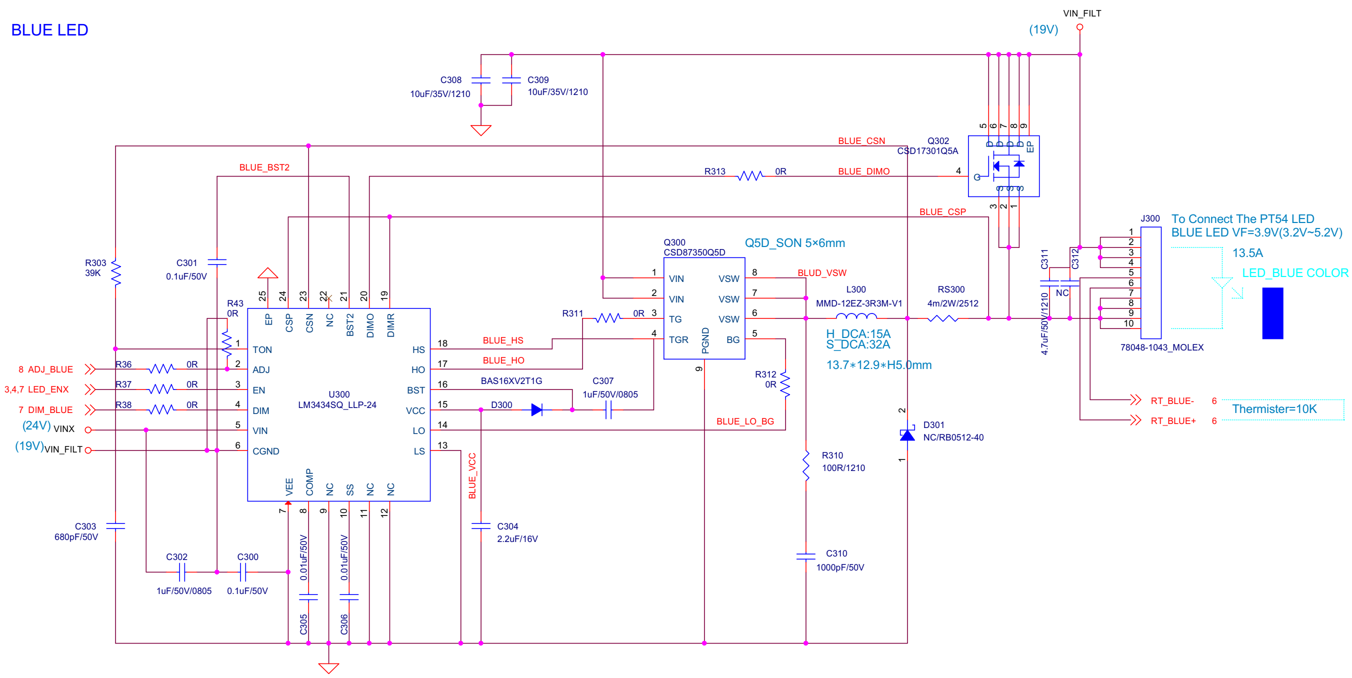


Figure 13. LM3434 Blue LED Driver Schematic

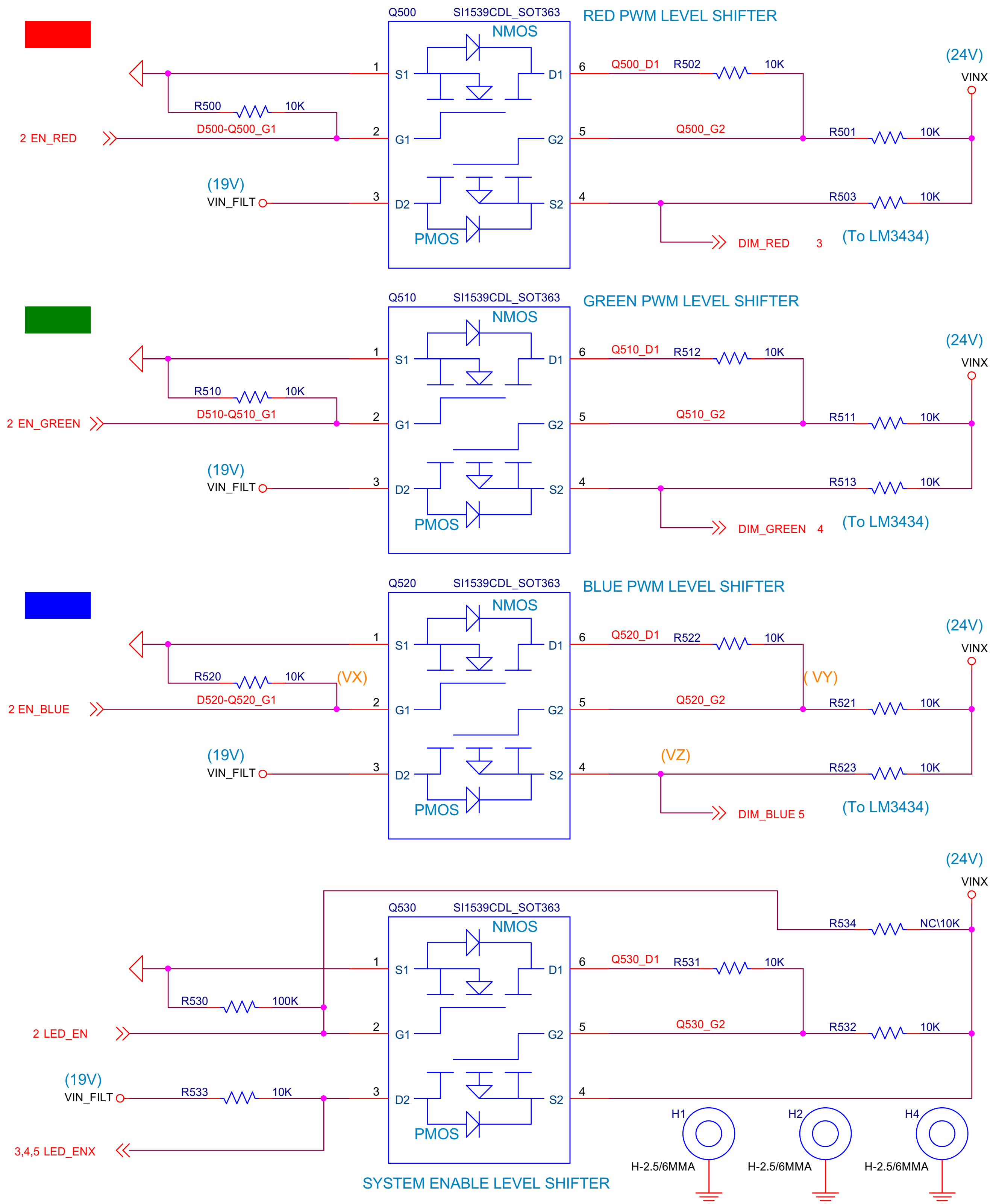


Figure 14. LM3434 LED DIM and EN Level-Shift Schematic

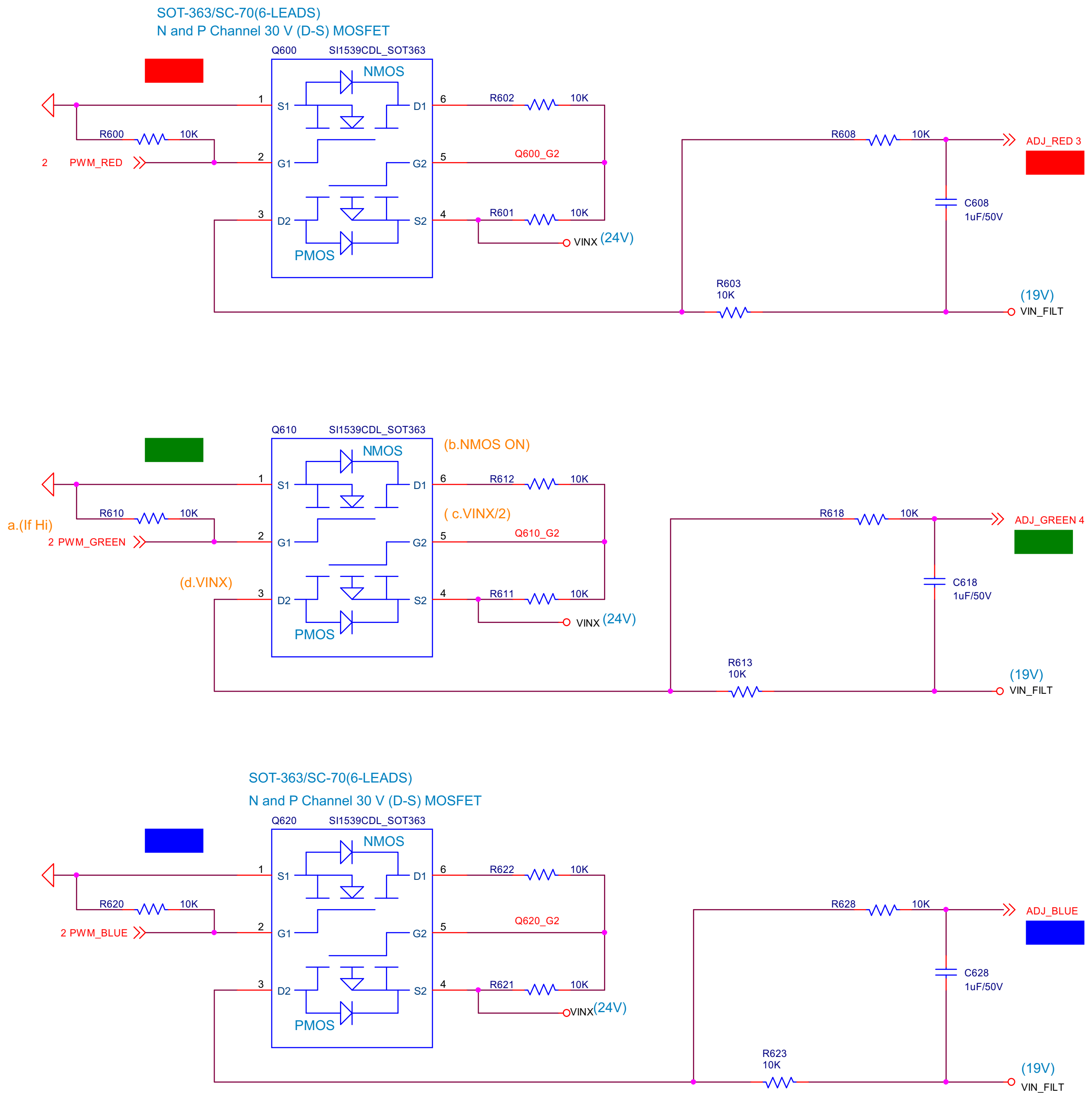


Figure 15. LM3434 ADJ Level-Shift Schematic

5.1 Bill of Materials (BOM)

Table 1. Bill of Materials (BOM)

Qty	ID	Part Number	Value	Description	Size	Vender
1	C13	STD	0.01µF	Capacitor, Ceramic	603	STD
1	C105	STD	0.01µF	Capacitor, Ceramic	603	STD
1	C106	STD	0.01µF	Capacitor, Ceramic	603	STD
10	C1, C2, C3, C4, C108, C109, C208, C209, C308, C309	STD	10µF	Capacitor, Ceramic	1210	STD
2	C10, C11	GRM31CR71H475KA12L	4.7µF	Capacitor, Monolithic Ceramic, 50VDC, ±10%	1206	Murata
6	C102, C107, C202, C207, C302, C307	GRM21BR71H105MA12L	1µF	Capacitor, Ceramic Chip, 50V, ±20%	805	Murata
3	C103, C203, C303	STD	1000 pF	Capacitor, Ceramic,	603	STD
3	C104, C204, C304	GRM188R61C225KE15D	2.2µF	Capacitor, Ceramic,	603	Murata
3	C110, C210, C310	STD	1000pF	Capacitor, Ceramic,	603	STD
1	C12	GRM21BR71E105MA99L	1µF	Capacitor, Ceramic, 25V, X7R, 15%	805	TDK
2	C14	STD	100pF	Capacitor, Ceramic,	603	STD
9	C100, C101, C200, C201, C300, C301, C608, C618, C628	STD	0.1µF	Capacitor, Ceramic,	603	STD
4	C205, C206, C305, C306	STD	0.01µF	Capacitor, Ceramic,	603	STD
1	D1	SMCJxxx[c]A-13-F	SMCJ22	Diode, [Uni-]Directional TVS, 1500W, xx-A, yy-V	SMC	Diodes
1	D10	MBR0540T	MBR0540T	Diode, Schottky, 0.5A, 40V	SOD-123	OnSemi
3	D100, D200, D300	BAS16XV2T1	BAS16XV2T1	Diode, Switching, 200 mA, 75V	SOD-523	On Semi
4	J1, J100, J200, J300	SD-87438-08xx	SD-87438-08xx	Header, SMT Right Angle 8 pin, 1.5 mm pitch	7.75x13.3 mm	Molex
1	J2	SD-78119-1188	SD-78119-1188	Conn, SMT Vertical 18 pin, 0.5mm Pitch	3.4x11.1 mm	Molex
1	L1	IHLP-1616BZ-11	0.22µH	Inductor, Dual SMT, yyA, zz mΩ	0.160 X 0.175 inch	Vishay
1	L10	LPS3008-xxxML	100µH	Inductor, SMT, yyA, zz-mΩ	0.116 x 0.116 inch	Coilcraft
3	L100, L200, L300	IHLP5050CEER3R3M01	3.3µH	Inductor, Low Profile High Current, yyA, ±20%	0.51 x 0.52 inch	Vishay
1	Q10	MMDT5401	MMDT5401	Transistor, NPN, Dual, 150V, 200mA	SOT-363	Diodes
3	Q100, Q200, Q300	CSD87350Q5D	CSD87350Q5D	MOSFET, Dual N-Chan, 30V 27A	QFN-8 POWER	TI
3	Q102, Q202, Q302	CSD17301Q5A	CSD17301Q5A	MOSFET, NChan, 30V, 100A, 2.9 mΩ	QFN-8 POWER	TI
7	Q500, Q510, Q520, Q530, Q600, Q610, Q620	Si1539CDL	Si1539CDL	MOSFET, N-Pch, 30V, 0.7A, 525 mΩ, 890 mΩ	SC-70	Vishay
1	R10	STD	12.1K	Resistor, Chip, 1/16-W, 1%	603	Std

Table 1. Bill of Materials (BOM) (continued)

Qty	ID	Part Number	Value	Description	Size	Vender
3	R103, R203, R303	STD	49.9K	Resistor, Chip, 1/16W, 1%	603	STD
3	R110, R210, R310	STD	100	Resistor, Chip, 1/2W, 0.1%	1210	STD
1	R13	STD	75K	Resistor, Chip, 1/16-W, 1%	603	STD
1	R14	STD	20K	Resistor, Chip, 1/16-W, 1%	603	STD
1	R15	STD	4.99K	Resistor, Chip, 1/16-W, 1%	603	STD
2	R16, R17	STD	61.9K	Resistor, Chip, 1/16-W, 1%	603	STD
32	R18, R500, R501, R502, R503, R510, R511, R512, R513, R520, R521, R522, R523, R531, R532, R533, R600, R601, R602, R603, R610, R611, R612, R613, R620, R621, R622, R623, R534, R608, R618, R628	STD	10K	Resistor, Chip, 1/16-W, 1%	603	STD
1	R530	STD	100K	Resistor, Chip, 1/16-W, 1%	603	Std
3	RS100, RS200, RS300	WSR2xxxFTA	0.004	Res, Power Metal Strip, 2W, ±x%	0.49 x 0.10 inch	Vishay Dale
1	U10	LM5002SD	LM5002SD	IC, High Voltage Switch Mode Regulator	QFN	TI
3	U100, U200, U300	LM3434SQ	LM3434SQ	IC, LED Driver with High Frequency Dimming	QFN	TI
16	R19, R20, R21, R22, R23, R24, R25, R26, R27, R28, R30, R31, R32, R33, R34, R35	STD	0R	Resistor, Chip, 1/16-W, 1%	603	STD

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.