LED Backlighting Solution with LM3430 and LM3432

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Introduction

Since the release of high brightness White LED (HB-WLED) in the middle of 1990's, tremendous research efforts have been undergoing to improve the emission efficiency, reliability and thermal packaging technologies in order to expand its range of applications. In the last few years, improvements in HB-WLED performance and price structure attracts more potential applications considering this new lighting source technology as an alternative to conventional one. One area of applications, LCD display backlighting, consider this new backlighting method as the ultimate solution to replace the existing Cold Cathode Fluorescent Lamps (CCFL). Backlight LED-driver solutions need to exhibit following characteristics:

- Instead of voltage control, LED-driver need direct LED current control to ensure consistent color and brightness;
- High conversion efficiency under various conditions;
- Support PWM dimming;
- Limit LED's rail voltage while LEDs open circuited;
- Ability to shutdown individual channel(s) when short or open circuited LED(s) detected;
- Device over temperature detect and shutdown;
- Low profile, small size and ease to use.

The LM3432 is a 6-channel high voltage current regulator which provides a simple solution for LED backlighting applications and the LM3430 is a companion device to supply high voltage required to drive serially connected LED strings. The LM3430 and the LM3432 provide a complete solution to most HB-WLED backlighting applications for notebook and PC monitor. In this application note, a typical example for a solution to drive six strings of twelve LEDs in series running at 20mA per string is described in details.

The Demonstration Board

The LM3432 is used to drive 6-channel LED strings with 12 LEDs in series per string running at 20mA. This example provides a simple solution for HB-WLED backlight applications in notebooks and monitors. The LM3432 is powered with its companion device, LM3430, the Dynamic Headroom Control (DHC) feature helps to provide the optimal system efficiency. The design specification for this demonstration board is shown in below:

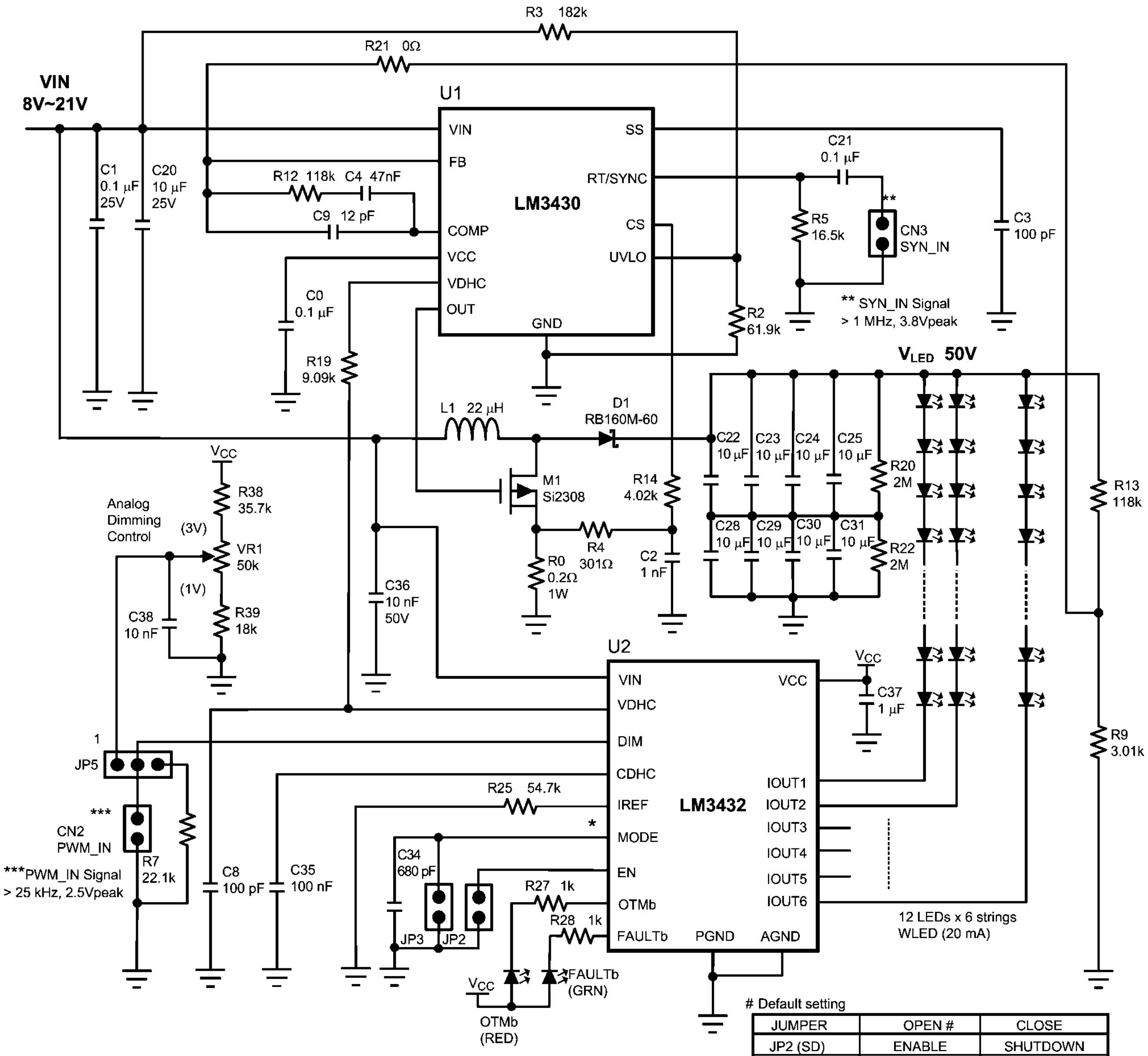
Design Specifications:

• Supply Voltage, VIN	6V to 21V
• Boost Converter Switching Frequency, F_{SW}	1 MHz
• Boost Converter Output Voltage, V_{LED} (With load disconnected)	50V
• Number of LED String	6
• Number of LED per String	12
• LED Current per String, I_{LED}	20 mA

PWM Dimming Function:

• Analog Dimming Mode	
Control Voltage Input, V_{PWM}	1V to 3V (0% to 100%)
Dimming Frequency, F_{PWM}	≅23 kHz
• Digital Dimming Mode	
External PWM Signal	20 kHz to 25 kHz, $2.5V_{peak}$

Demonstration Board Schematic



Default setting

JUMPER	OPEN #	CLOSE
JP2 (SD)	ENABLE	SHUTDOWN
JP3 (MODE)	ANALOG DIM	DIGITAL DIM
	1-2 #	2-3
JP5	ANALOG_IN	DIGITAL_IN

* By connecting the MODE pin to ground with an external capacitor, the Analog Dimming function will be enabled. The capacitance of the external capacitor determines the PWM Dimming frequency and the applied DC voltage to PWM pin controls the duty ratio of LED current.

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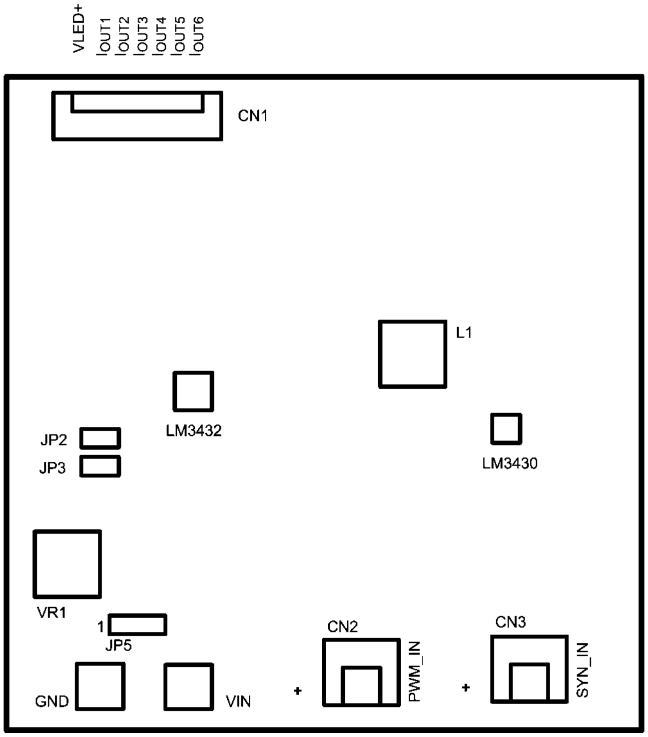
Connecting the Demonstration Board to LED Panel



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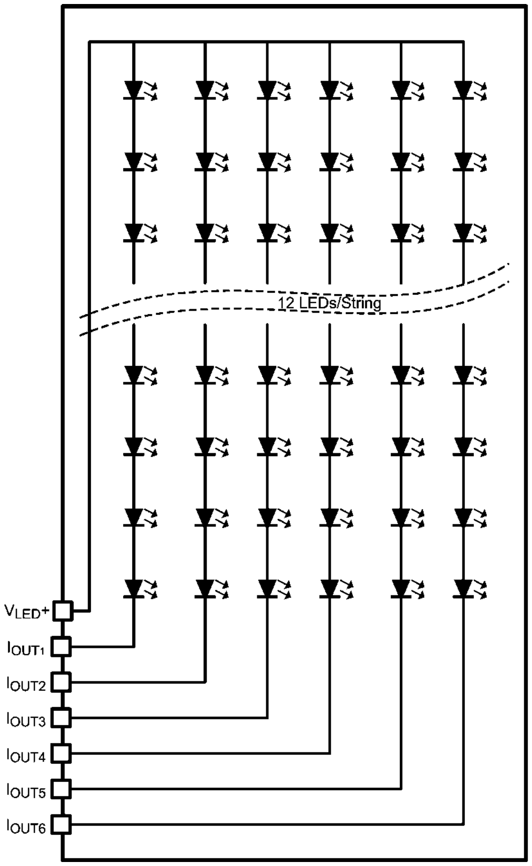
LM3430+LM3432 Demonstration Board



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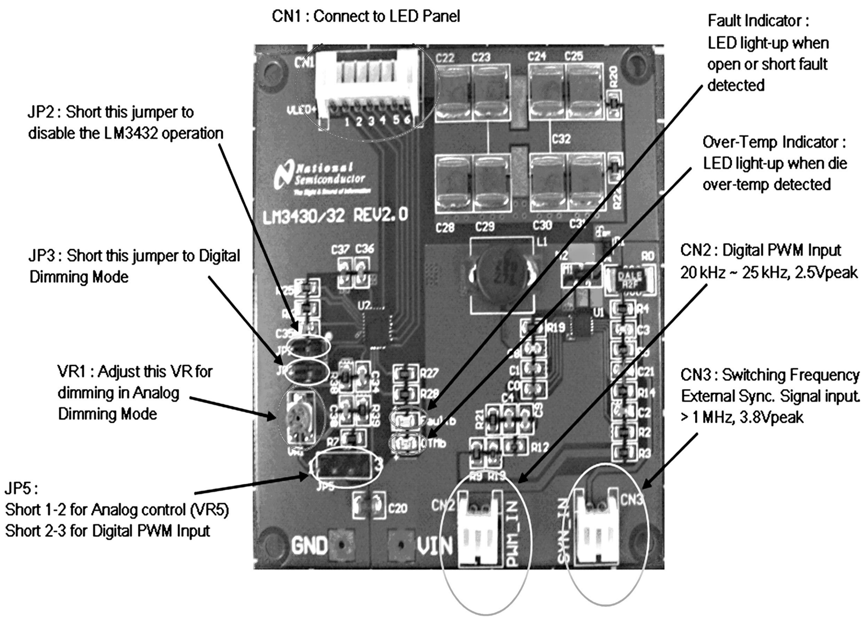
LED Panel (6 x 12 LEDs)

Connecting the demonstration board outputs to the LED panel is simple; just use a flat cable connecting the output header, CN1 to the respective input points of the LED panel as shown in above diagram. The LED panel is not a part with this demonstration kit; the user needs to build the LED panel for evaluation.

Configuration of the Demonstration Board for Evaluation



CN1 : Connect to LED Panel

JP2 : Short this jumper to disable the LM3432 operation

JP3 : Short this jumper to Digital Dimming Mode

VR1 : Adjust this VR for dimming in Analog Dimming Mode

JP5 :
Short 1-2 for Analog control (VR5)
Short 2-3 for Digital PWM Input

Fault Indicator : LED light-up when open or short fault detected

Over-Temp Indicator : LED light-up when die over-temp detected

CN2 : Digital PWM Input
20 kHz ~ 25 kHz, 2.5Vpeak

CN3 : Switching Frequency External Sync. Signal input.
> 1 MHz, 3.8Vpeak

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Analog PWM Dimming Mode

- Leave jumper JP3 open to enable the Analog Dimming Mode;
- Short pins 1-2 of jumper JP5 to select the Analog control input;
- The VR1 is used to derive the analog control voltage from LM3432's VCC output (5V nominal) and pass to LM3432's DIM input pin to control the dimming of the LED;
- Adjust VR5 to change the LED brightness. The ON current of the LED is still maintained, only the duty ratio of ON time is adjusted to achieve the effect of dimming. This ensures the correct color is preserved even in dimmed output conditions.

Digital PWM Dimming Mode

- Short jumper JP3 to enable the Digital Dimming Mode;
- Short pins 2-3 of jumper JP5 to select the Digital control input;
- The external PWM dimming control signal applied to CN2 is then routed to LM3432's DIM input pin;
- The control of LED current ON-OFF is passed to the externally applied PWM dimming control signal. The ON duty of the PWM control signal governs the LED brightness.

Connect Power Supply to the Demonstration Board

Input supply voltage, V_{IN} is connected to the V_{IN} and GND solder pads of the demonstration board. V_{IN} ranges from 8V to 21V. Once the power is applied, all LEDs on the LED panel will be lighted up. The default setting of the demonstration board is in analog dimming mode, by adjusting the potentiometer, VR1; the LED brightness can be adjusted accordingly.

For some cases, due to the incorrect power-up sequence timing of the LM3430 and the LM3432, some strings may have problem at cold start-up and the LM3432's fault detect may be falsely triggered. The normal operation can be recovered by shorting JP2 for few mini-seconds to reset the LM3432's fault detect circuit. This condition only happens when the board is powered up with LEDs in maximum brightness. This condition is not common in most backlighting applications. Typical applications normally have some sort of power-up sequence control to make sure the high voltage supply from the LM3430 is available before the LM3432 is being enabled.

Synchronization of the Multiple Boost Converters

In certain applications, more than one LED rail voltages are required in a single system. For example, a RGB backlighting system requires at least two different LED rail voltages, one for RED and one for BLUE and GREEN. Multiple switching converters running at slightly different switching frequency can introduce complex EMI situation. In order to accommodate this problem, the LM3430 can be synchronized to an external master clock that drives all boost converters switching at one single frequency. The external clock must running at a higher frequency than the preset free running oscillator frequency, i.e. > 1 MHz with this demonstration board. This feature can be enabled by applying external synchronization signal to CN3; the device will pass the control to the external synchronization signal automatically.

Dynamic Headroom Control

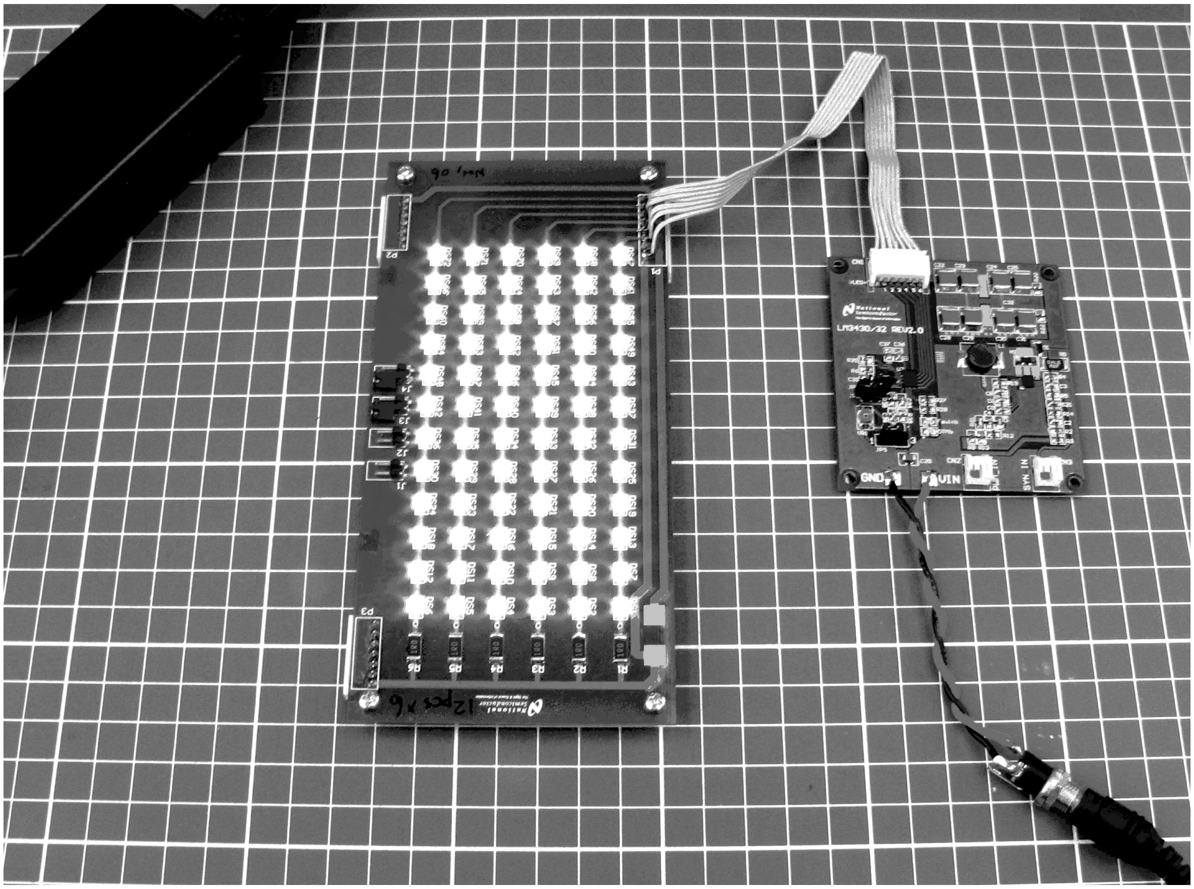
With the LM3432's VDHC output pin connected to LM3430's VDHC input pin through a gain setting resistor (R19), the Dynamic Headroom Control (DHC) function will be in operation. The LM3432's DHC function will interact with the LM3430 to adjust the boost converter output voltage, VLED to LED strings just enough to keep all LED strings current in regulation. This minimum headroom voltage across the LED strings guarantees the best achievable system efficiency.

LED OPEN and SHORT Fault Indication

The LM3432 has the ability to detect both OPEN and SHORT faults of LEDs string by string. Whenever a fault is detected, the respective LED string will be latched OFF to protect the device from any possible damage and a signal will be issued to communicate with system micro-controller for appropriate actions. The SHORT fault detect threshold is 7.9V (typical) across IOUT pin to ground and OPEN fault check for zero sink current in any channel for more than 50 µs during ON duty. The fault output, FAULTb pin is connected to an indicator LED in the demonstration board.

Over-Temperature Monitor and Shutdown

If the on-die temperature is over 125°C, the OTMb pin will be pulled to ground to inform the system micro-controller for immediate attention. Corrective action is expected to lower the die temperature, for example, the system can reduce the PWM duty factor to lower the average current into the IOUTs. If the on-die temperature rises further to 165°C, the LM3432 will shutdown all channels to prevent any potential damage to the device. When the device is cooled down to about 145°C, normal operation will resume. Again, in the demonstration board, the over-temperature signal output, OTMb pin is connected to an indicator LED.



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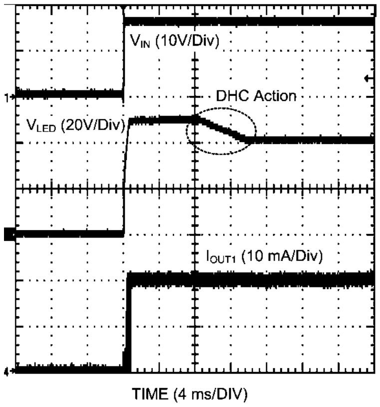
Demonstration Board in Operation (Powered by a Notebook Adapter)

Typical Operating Waveforms

In below some operating waveforms are presented for reference. The demonstration board is powered by a note-book adaptor with nominal output voltage of 16VDC.

Power-Up



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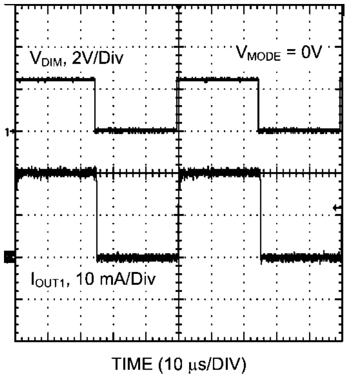
Digital Dimming Operation (Channel 1 Waveform)



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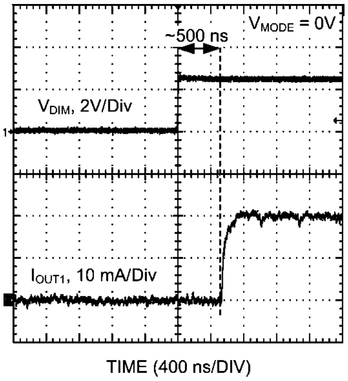
PWM Dimming Characteristic Rising Edge (Channel 1 Waveform)



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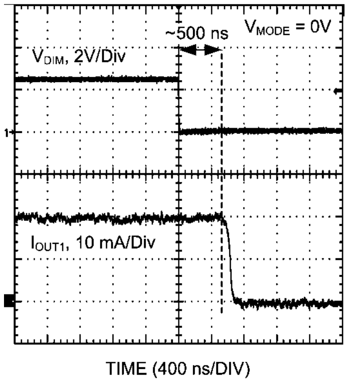
PWM Dimming Characteristic Falling Edge (Channel 1 Waveform)



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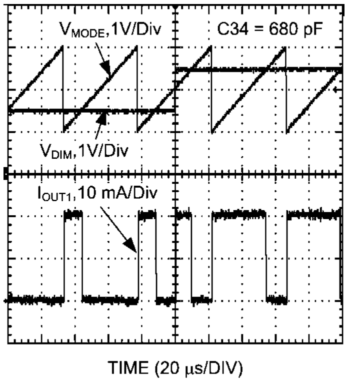
Analog PWM Dimming Operation



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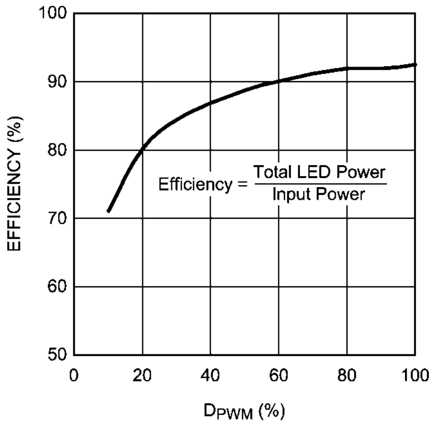
Efficiency



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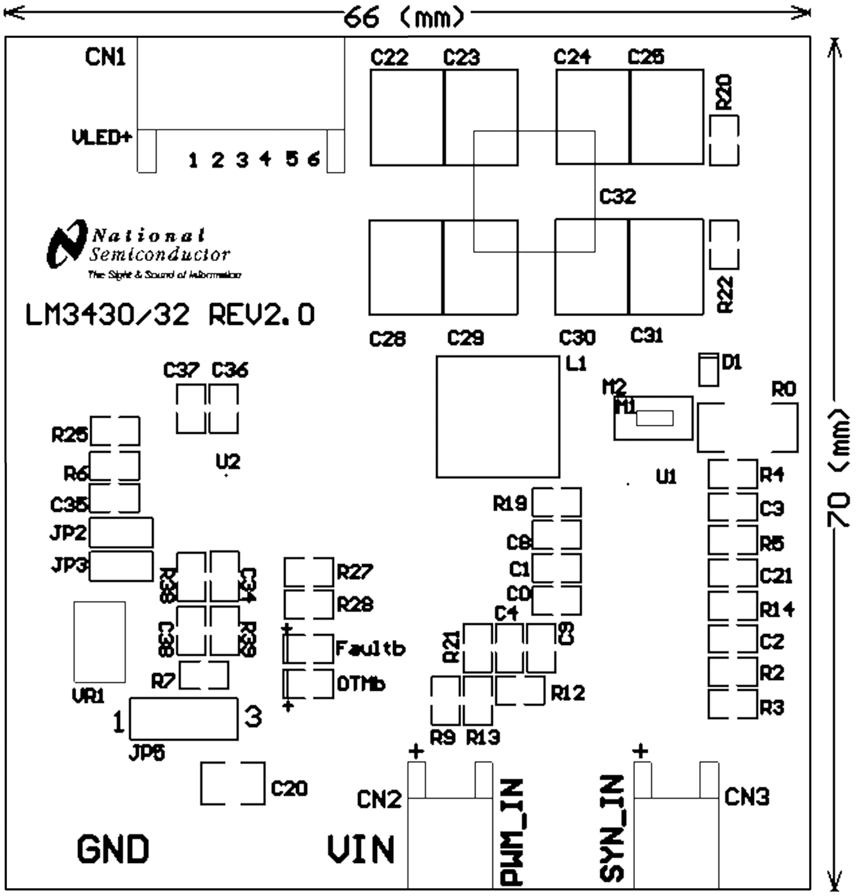
PCB Layout



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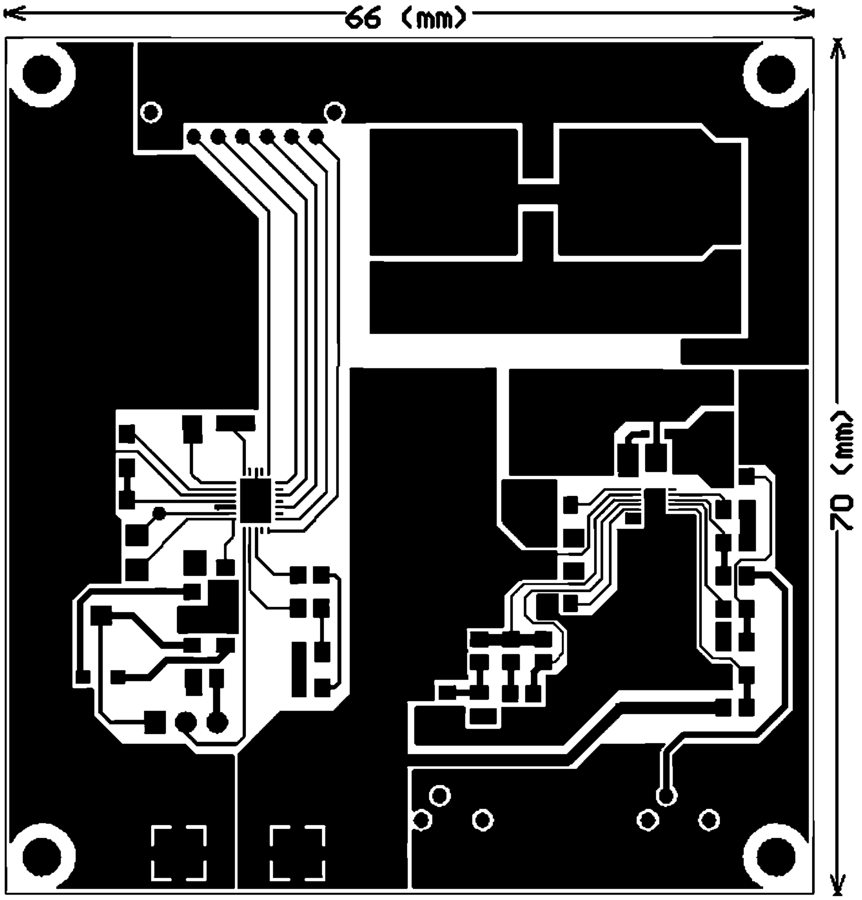
LM3430+LM3432 Demonstration PC Board Top Overlay



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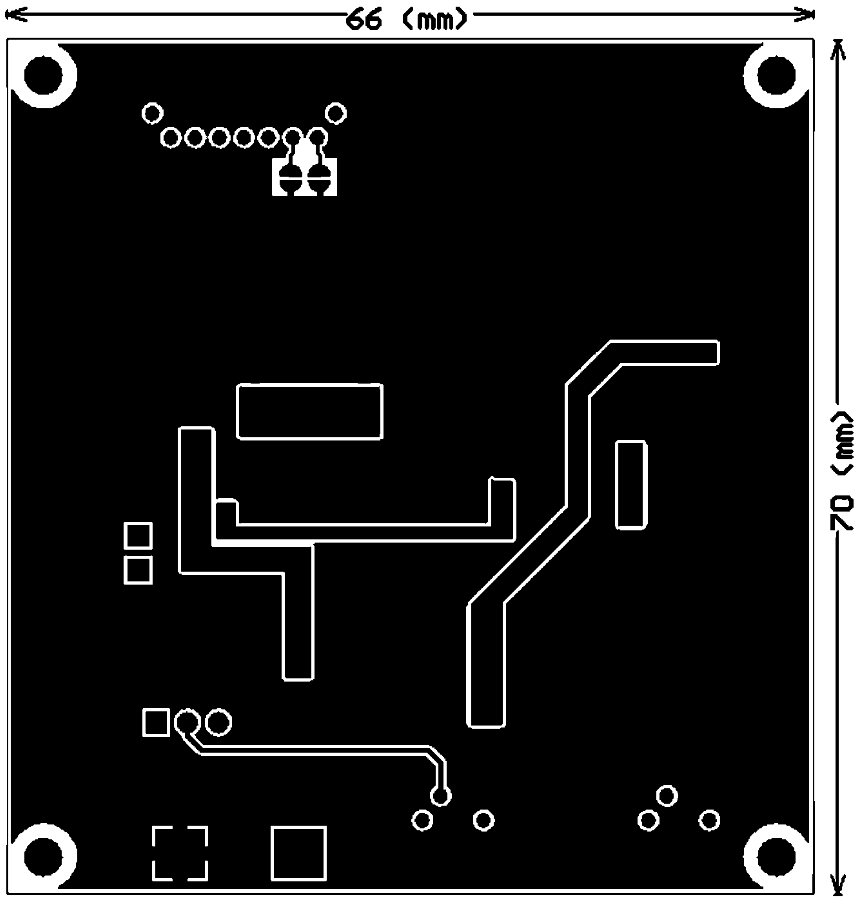
LM3430+LM3432 Demonstration PC Board Top Layout



LM3430+LM3432 Demonstration PC Board Bottom Layout

Bill of Materials for the Demonstration Board

Designation	Type	Part Number	Value	Package	Qty	Manufacturer
Boost Converter Section (LM3430) :						
U1	Controller IC	LM3430		LLP-12	1	NSC
M1	N-MOSFET	SI2308DS	60V, 125 mΩ, 4.8nC	SOT-23	1	Vishay
D1	Schottky Diode	RB160M-60	60V, 1A	SOD-123	1	Rohm
L1	Power Inductor	CDRH8D28NP-220NB	22 µH, 1.6A	8.3x8.3x3mm	1	Sumida
C20	Ceramic Capacitor	ECJ3YB1E106M	10 µF, 25V	1206	1	Panasonic
"C22 - C25 C28 - C31"	Ceramic Capacitor	GRM55DR61H106KA88L	10 µF, 50V	2220	8	MuRata
C0, C1, C21	Ceramic Capacitor	"GRM188R71E104KA01B (ECJ1VB1E104K)"	0.1 µF, 25V, X7R	0603	3	"MuRata (Panasonic)"
C2	Ceramic Capacitor	"GRM1885C1H102JA01B (ECJ1VB1H102K)"	"1 nF, 50V, COG (1nF, 50V, X7R)"	0603	1	"MuRata (Panasonic)"
C3, C8	Ceramic Capacitor	GRM1885C1H101JA01B	100 pF, 50V, COG	0603	2	Murata
C4	Ceramic Capacitor	"GRM188R71E473KA01B (ECJ1VB1E473K)"	47 nF, 25V, X7R	0603	1	"MuRata (Panasonic)"
C9	Ceramic Capacitor	GRM1885C1H120JA01B	12 pF, 50V, COG	0603	1	Murata
R0	Resistor	WSL2512R20000FEA	0.2Ω, 1W	2512	1	Vishay
R2	Resistor	CRCW06036192F	61.9 kΩ, ±1%	0603	1	Vishay
R3	Resistor	CRCW06031823F	182 kΩ, ±1%	0603	1	Vishay
R4	Resistor	CRCW06033010F	301Ω, ±1%	0603	1	Vishay
R5	Resistor	CRCW06031652F	16.5 kΩ, ±1%	0603	1	Vishay
R9	Resistor	CRCW06033011F	3.01 kΩ, ±1%	0603	1	Vishay
R12, R13	Resistor	CRCW06031183F	118 kΩ, ±1%	0603	2	Vishay
R14	Resistor	CRCW06034021F	4.02 kΩ, ±1%	0603	1	Vishay
R19	Resistor	CRCW06039091F	9.09 kΩ, ±1%	0603	1	Vishay
R20, R22	Resistor	CRCW06032004F	2.0 MΩ, ±1%	0603	2	Vishay
R21	Resistor	CRCW06030R00F	0Ω, ±1%	0603	1	Vishay

Designation	Type	Part Number	Value	Package	Qty	Manufacturer
Current Control Section (LM3432) :						
U2	LED Current Regulator IC	LM3432		LLP-24	1	NSC
C34	Ceramic Capacitor	GRM1885C1H681JA01B	680 pF, 50V, COG	0603	1	MuRata
C35	Ceramic Capacitor	"GRM188R71E104KA01B (ECJ1VB1E104K)"	0.1 µF, 25V, X7R	0603	1	"MuRata (Panasonic)"
C36, C38	Ceramic Capacitor	"GRM188R71H103KA01B (ECJ1VB1H103K)"	10 nF, 50V, X7R	0603	2	"MuRata (Panasonic)"
C37	Ceramic Capacitor	"GRM188R61A105KA61B (ECJ1VB1A105K)"	1 µF, 10V, X5R	0603	1	"MuRata (Panasonic)"
R7	Resistor	CRCW06032212F	22.1 kΩ, ±1%	0603	1	Vishay
R25	Resistor	CRCW06035472F	54.7 kΩ, ±1%	0603	1	Vishay
R27, R28	Resistor	CRCW06031001F	1.0 kΩ, ±1%	0603	2	Vishay
R38	Resistor	CRCW06033572F	35.7 kΩ, ±1%	0603	1	Vishay
R39	Resistor	CRCW06031802F	18.0 kΩ, ±1%	0603	1	Vishay
VR1	Variable Resistor	PVM4A5003C01B00	0 - 50 kΩ, 4mm		1	MuRata
FAULTb	SMD LED		GREEN	0805	1	
OTMb	SMD LED		RED	0805	1	
JP2, JP3	Jumper Header		2-pin, 2.54mm pitch		2	
JP5	Jumper Header		3-pin, 2.54mm pitch		1	
CN1	Connector Header		7-pin, 2mm pitch		1	
CN2, CN3	Connector Header		2-pin, 2mm pitch		2	

Design Hints

The schematic of the demonstration board is shown in page 2. Some hints on selection of the key parameters and components will be described in below. For full details of the design equations and theories, please refer to the LM3430 and LM3432 datasheets.

BOOST CONVERTER DESIGN WITH LM3430

The function of the boost converter is to step up the input voltage to a higher LED rail voltage to drive strings of twelve LEDs connected in series.

Determination of the Worst Case LED Rail Voltage, V_{LED}

The diode forward voltage, V_F of HB-WLED ranges from 3.5V to 4.0V that varies from vendor to vendor. Considering only the worst case situation, i.e. $V_F = 4.0V$, for twelve LEDs connected in series, a minimum of 48V is required to put the LED strings in proper operation. On the top of this voltage, additional control headroom for the constant current regulators is needed. The suggested start up LED rail voltage is 50V and this is also the ceiling of the boost converter output voltage, i.e. in case the load is disconnected, the boost converter output will stay at this voltage, no risk of over-voltage need to be considered. Once the demonstration board is in operation, the LM3432 will communicate with the LM3430 to lower the LED rail voltage to an appropriate level. This feature makes the LM3430 with LM3432 a robust and efficient LED driver solution.

Selecting the Switching Frequency, F_{SW}

The selection of switching frequency is a trade off between size, cost and efficiency. In general, a lower switching frequency requires larger and more expansive external components. For some of the applications, space is one of the key considerations. A higher switching frequency can fulfill the space requirement, however the switching losses will go up and the overall system efficiency will be lowered. In this demonstration board, a switching frequency of 1MHz was selected.

Selection of the Power MOSFET

The power MOSFET plays a key role in system efficiency. An ideal power MOSFET should be low gate capacitance, C_{iss}, low gate charge, Q_g, low ON resistance, $R_{DS(ON)}$ and sufficient Drain-Source breakdown voltage, $V_{DS(BD)}$. In this application, the required $V_{DS(BD)}$ is 50V plus the Schottky diode voltage drop, typically its about 0.5~0.7V. The average load current with all LED strings fully ON is 120 mA, by quick estimation; the worst case peak switch current is about 0.9A. The tiny MOSFET selected can operate up to 60V and 2A with $R_{DS(ON)} = 125\ m\Omega$, $Q_g = 4.8$ nC and $C_{iss} = 240$ pF.

Selecting the Boost Schottky Diode

The boost Schottky diode current equals to the average load current. The forward voltage drop and reverse recovery time determines the power loss with this component. The lower the forward voltage drop and faster reverse recovery time always results in better performance. The Schottky diode must also be rated to handle the maximum output voltage plus any ringing at the switching node caused by the diode parasitic capacitance and lead inductance.

Selection of Power Inductor

In fixed switching frequency boost converter applications, the inductance is determined by the allowable peak-to-peak inductor ripple current, $\Delta i_{L(p-p)}$ of the maximum load current and the switching frequency. The duty cycle, D is evaluated first at both $V_{IN(MIN)}$ and $V_{IN(MAX)}$. Then the full load average inductor current is calculated at both voltages respectively. With the maximum average inductor current, the allowable inductor ripple current is determined. Finally, the inductance value can be calculated and an off-the-shelf inductance value closest to the calculated value must be selected. The calculation only gives the inductance required but not the size of the inductor, the inductor selected must be capable to handle the maximum peak inductor current without saturating the inductor even at high temperature. The maximum peak inductor current is equal to the maximum average inductor current plus one half of the maximum allowable inductor ripple current, $\Delta i_{L(p-p)}$.

Selection of Output Capacitor

The output capacitor in a boost converter supplies current to the load during the MOSFET on-time and filters the AC components of the load current during the off-time. The selection of this capacitor determines the steady state output voltage ripple, ΔV_{OUT}. The magnitude of this voltage ripple is comprised of three components. The first part of the ripple voltage is the surge current created during the boost diode turns on. The second part is due to the charging and discharging of the output capacitor through the boost diode and the final part is caused by the flow of inductor current through the output capacitor's Equivalent Series Resistance, ESR. Both part 1 and part 3 are related to ESR, in case low ESR ceramic capacitors are used, the contribution of these two parts becomes insignificant. The output voltage ripple can be estimated by the equation in below.

$$\Delta V_{OUT} = \frac{I_{OUT} D}{C_{OUT} F_{SW}}$$

Where I_{OUT} is the load current, D is the duty ratio and F_{SW} is the converter switching frequency.

From the equation in above, the relationships between different parameters are obvious. A higher output capacitance can reduce the output voltage ripple; however this can slow down the power-up time and the system transient respond. The choice of the output capacitor depends mainly on the application specifications. For most of the cases, multiple iterations are required to come up with an appropriate value.

Selecting the Current Sensing Resistor

The current sensing resistor, R_{SNS} is used for steady state regulation of the inductor current and to provide cycle by cycle current limit function. The resistance selected must be low enough to keep the power dissipation to a minimum and still can maintain good signal-to-noise ratio for the current sensing circuitry. The current limit comparator's threshold is 0.5V. The resistance should be selected so that the switching cycle can be terminated before the inductor current exceeds the saturation rating of the inductor. The required resistor calculation must take into account of both the switch current through the sensing resistor and the compensation ramp current flowing through the internal 2 kΩ resistor and external current sensing network resistors. The worst case average power dissipation in the current sensing resistor, P_{SNS} can be estimated by the equation in below.

$$P_{SNS} = \left[\left(\frac{I_{OUT}}{1 - D_{MAX}}\right)^2 R_{SNS}\right] D_{MAX}$$

Where the D_{MAX} is the On Duty Ratio with the input voltage is a minimum.

The Control Loop Compensation

The control loop is comprised of two parts. The first part is the power stage, which consists of the pulse width modulator, the output filter and the load. The second part is the error amplifier which is realized by an op-amp configured as an inverting amplifier. To close the control loop, compensation is required to ensure stability and optimize system performance. Many techniques exist for selecting the compensation network components. The most popular method is to create the Bode plots of gain and phase for the power stage and error amplifier individually. By combining both stages, the open loop system Bode plots resulted. By using the plots, overall bandwidth, gain margin and phase margin of the regulator can be easily determined. Software tools such as MathCAD, Matlab and Excel can be used to observe how the changes in compensation network and power stage affecting the system gain and phase. One approach to select the compensation network is introduced in the LM3430 datasheet in details. The theoretically calculated compensation network can only be used as the starting point and bench testing and fine tuning is required to come up with the final values. With the demonstration board, a type II compensation network is suggested and the respective component values are listed in below:

Power Stage:

$L = 22\ \mu H$

$R_{OUT} = 417\Omega$

$C_{OUT} = 22\ \mu F$

$R_{ESR} = 350 m\Omega$

$R_{SNS} = 0.2\Omega$

$F_{SW} = 1\ MHz$

Output Voltage Feedback Divider:

R13 = 118 kΩ

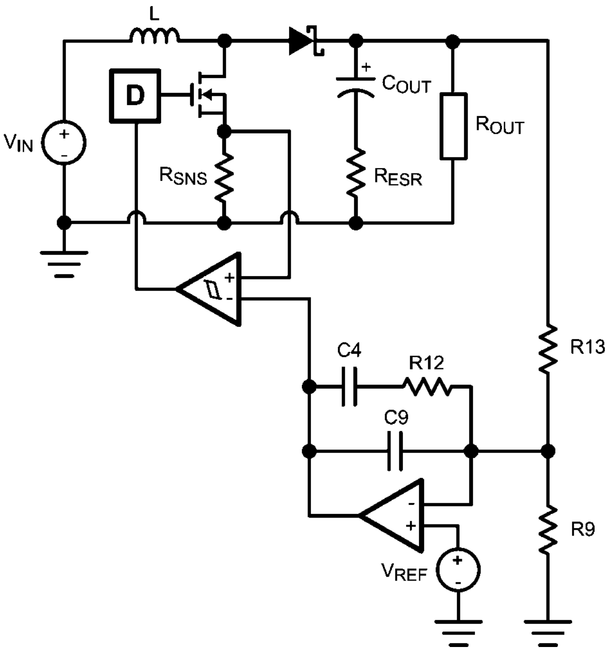
R9 = 3.01 kΩ

Compensation Network:

R12 = 118 kΩ

C4 = 47 nF

C9 = 12 pF



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Power Stage Amplifier

CURRENT REGULATOR DESIGN WITH LM3432

The LM3432 provides a simple and handy solution to drive strings of serially connected LEDs with precisely controlled constant current. Only couple of external passive components, up to about 120 LEDs in six strings can be lighted up. To control the brightness of the LED strings, both analog and digital dimming method can be used.

Programming the LED Current

The string current can be programmed by an external resistor, R_{IREF} connected across IREF pin and GND. The equation to calculate the resistance is:

$$R_{IREF} = \frac{1.094}{I_{OUT}} \text{ in k}\Omega$$

With this demonstration board, the string current is 20 mA and the resistor is R25. Applying to the equation:

$$R25 = \frac{1.094}{20\ mA} = 54.7\ k\Omega$$

Determination of the Analog Dimming Frequency

In analog dimming mode, the internally generated PWM frequency is controlled by the external capacitor, C_{MODE} connected across MODE pin and GND. The equation that governs the relationship is:

$$f_{PWM} = \frac{1.65 \times 10^{-5}}{C_{MODE}}$$

Where C_{MODE} is in Farads and F_{PWM} is in Hz.

In this demonstration board, the capacitor to determine the PWM frequency is C34 and the capacitance used is 680 pF. The PWM frequency is:

$$f_{PWM} = \frac{1.65 \times 10^{-5}}{680\ pF} = 24.3\ kHz$$

Selection of Gain Setting Resistor for Dynamic Headroom Control

By connecting the VDHC pin of LM3432 through a gain setting resistor to the VDHC pin of the LM3430, the LM3432's DHC function will regulate the LED rail voltage from the boost converter to a level just enough to keep all LED strings current in regulation. This gain setting resistor, R19 determines the maximum depth of the rail voltage can be lowered. The rule of thumb on the selection of this resistor is about three times of the resistance of the bottom resistor in the LM3430 output voltage feedback resistor divider. That approximately allows the rail voltage lowered by one-quarter of the preset boost converter output voltage. In this example, the bottom feedback resistor, R9 is 3.01 kΩ, the gain setting resistor, R19 used is 9.09 kΩ. The small capacitor, C8 connected to the VDHC output pin is for noise filtering, a 100pF capacitor is good enough.

The capacitor C35 connected to VDHC pin controls the DHC function respond time, the value needed depends on the PWM dimming frequency. In our demonstration board, the PWM frequency is about 20 kHz, a 100 nF capacitor is used. The DHC function must be kept slow enough to avoid false triggering of the protection logics and fast enough to respond to high PWM dimming frequency with narrow ON pulse width. Bench side testing is required to determine the optimum value for specific requirements

REFERENCE DOCUMENTS

Document Number/Type	Title
Datasheet	LM3430 Boost Controller for LED Backlighting
Datasheet	LM3432 6-Channel Current Regulator for LED Backlight Application
AN-1529	LM3430 Evaluation Board

Notes

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