Six-Channel
Led Driver Demoboard

General Description

The HV9957 LED driver combines a switch-mode boost converter and six low-dropout linear current regulators to provide the advantages of high efficiency with precise current control.

Features

- ► Phased dimming
- ► Temperature-triggered faulty LED protection
- ► Smart ‘outlier’ faulty string discrimination
- ► Overcurrent protection
- ► Precise dimming frequency
- ► Accurate channel matching

Configuration options

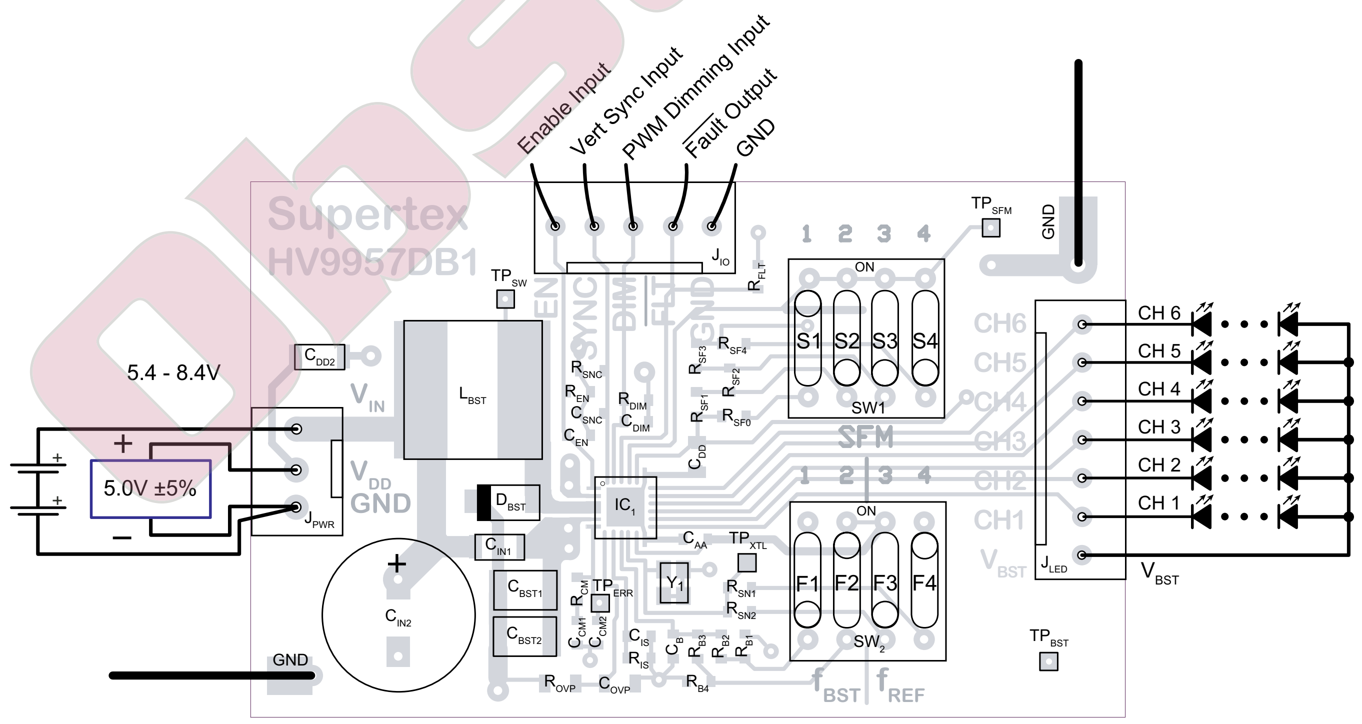
Four reference sources for LED drive frequency including external V_{SYNC} signal.

Eleven scaling factors, reference frequency to LED drive frequency

Four boost converter switching frequencies

Specifications	
V_{IN}	5.4 to 8.4V (2 cell Li-ion)
V_{DD}	5.0V±5%
V_{BST} (maximum string voltage + 0.9V)	up to 56V
Efficiency:	up to 87%
I_{LED} (six channel average, 100% duty cycle)	20mA±2%
Current matching (PWM average, maximum deviation from six channel average) @ 100% duty cycle @ 2% duty cycle	 ±2.0% ±2.0%
Dimming duty cycle jitter	±0.06%
Dimming PWM frequency Precision oscillator Crystal oscillator	 9600Hz ±0.5% 9600Hz ±10ppm
Dimensions	57mm X 35mm

Board Layout and Connections



Connections:

Power (three-pin)

VIN
Supplies the boost converter, which in turn provides the voltage needed to drive the LED strings. Configured to operate directly from a two-cell Li-ion battery at 5.4 - 8.4V.

VDD
Supplies the HV9957. 5.0V ±5%

GND
Circuit common.

Control (five-pin)

EN
Activates the HV9957 when a logic high voltage is applied.

When toggled low for <10µs, resets the Fault indicator output without interrupting driver operation.

SYNC
A logic level signal applied to this input establishes the PWM dimming frequency. Dimming frequency is the product of the SYNC frequency and the SFM value.

When no signal is applied, the dimming frequency is determined via the f_{REF} setting. No signal is defined as f_{SYNC} < 55Hz, including DC.

DIM
The duty cycle of the signal applied to this pin controls the duty cycle of the LED drive on a 1:1 basis. The frequency of the DIM signal does not control LED drive frequency unless the SYNC signal is absent and the f_{REF} switches are set to DIM.

$\overline{\text{FLT}}$
Open-drain output that goes low when a fault occurs. It is latched and is reset when the Enable (EN) input is toggled OFF then ON.

Short and long strings are disabled by die temperature rather than voltage. Strings are turned OFF only when necessary.

Fault conditions are:

Over-Current Protection (OCP)
Cycle-by-cycle boost switch current limiting

Over-Temperature Protection (OTP1, OTP2)
Two-stage temperature protection.

OTP1 attempts to reduce temperature by disabling channels having short or long LED strings (long strings take priority). Disabled channels are re-enabled by toggling Enable.

OTP2 is activated if OTP1 fails to reduce die temperature, shutting down all channels and the boost converter. Operation resumes once the die cools. Those channels previously identified as short or long remain disabled.

Open LED Protection (OLP)
Disables channels with an open string.
Triggered by boost converter overvoltage protection.

Shorted LED Protection (SLP)
Disables channels with low LED string voltage. Triggered by OTP1.

Long LED Protection (LLP)
Disables channels with high LED string voltage.
Triggered by OTP1.

GND
Circuit common.

LED (seven-pin)

CH1 – CH6
Channel outputs for driving the strings of LEDs. Nominally a 20mA current sink that is pulse width modulated via the DIM input to control LED brightness.

The demo board is configured for LED strings having a 50V drop or less.

The channel outputs are phased 60° apart. If one or more channels are disabled due to a fault, the phase angles of the remaining channels are equally distributed.

VBST
The boost converter output supplying the LEDs. Voltage is regulated to maintain at least 900mV at the channel outputs.

Switch Settings

f_{BST}-
F1 F2
Selects the boost converter frequency. Normally, f_{BST} is based on an internal time reference. If a crystal is used to set f_{REF}, the crystal is also used to set f_{BST}.

F1	F2	f_{BST}	
		f_{REF} SW <> 11	f_{REF} SW = 11
0	0	500kHz	512kHz
0	1	375kHz	384kHz
1	0	1.0MHz	1.024MHz
1	1	750kHz	768kHz

Certain components, especially the boost inductor, may need to be changed when a frequency other than 1.0MHz is selected. Alternatively, a lower input voltage may be used at lower frequency, albeit at a lighter load capability.

f_{REF}

F3 F4

Selects the source of the LED drive frequency when the SYNC signal is absent.

The reference frequency f_{REF} is multiplied by the SFM value to obtain the LED PWM drive frequency.

F3	F4	Mode	f_{REF}	Description
0	0	illegal	—	Do not select
0	1	RSYNC	60Hz	Precision resistor-tuned oscillator
1	0	XTAL	60Hz	Crystal oscillator
1	1	DIM	$f_{DIM}/9$ (SFM = 1) f_{DIM} (SFM > 1)	Dimming input frequency

SFM

S1 – S4

Selects the Sync Frequency Multiplier (SFM), which multiplies the selected reference frequency (f_{REF}) to obtain the LED PWM dimming frequency.

S1	S2	S3	S4	SFM
0	0	0	1	1
0	0	1	1	17
0	0	1	0	23
0	1	1	1	32
0	1	0	1	45
1	0	0	1	62
1	1	0	1	85
1	0	1	0	117
1	0	0	0	160
1	1	1	0	221
0	1	0	0	307
1	1	0	0	410

LED drive frequency is given by the following equation.

$$f_{PWM} = SFM \cdot f_{REF}$$

where SFM is the value from the table above
f_{REF} is the value from the table to the left

The table on Page 4 shows various LED PWM frequencies for the switch settings given in the orange and pink cells (f_{REF} and SFM), and the conditions specified in the blue and purple cells.

LED PWM Drive Frequencies

SFM switch				SYNC input	Signal present (>48Hz)				Signal absent (<48Hz)		
				f_{REF} F3:F4	don't care				0:1	1:0	1:1
				f_{REF} source	SYNC				R-Osc	Xtal	DIM pin
S1	S2	S3	S4	SFM	f_{SYNC} = (Hz)				R_{Osc} = (kΩ)	f_{Xtal} = (MHz)	f_{DIM} = (Hz)
					60	120	180	240	200	24.576	540
0	0	0	1	1	60	120	180	240	60	60	540
0	0	1	1	17	1,020	2,040	3,060	4,080	1,020	1,020	1,020
0	0	1	0	23	1,380	2,760	4,140	5,520	1,380	1,380	1,380
0	1	1	1	32	1,920	3,840	5,760	7,680	1,920	1,920	1,920
0	1	0	1	45	2,700	5,400	8,100	10,800	2,700	2,700	2,700
1	0	0	1	62	3,720	7,440	11,160	14,880	3,720	3,720	3,720
1	1	0	1	85	5,100	10,200	15,300	20,400	5,100	5,100	5,100
1	0	1	0	117	7,020	14,040	21,060	28,080	7,020	7,020	7,020
1	0	0	0	160	9,600	19,200	28,800	38,400	**9,600**	**9,600**	**9,600**
1	1	1	0	221	13,260	26,520	39,780	53,040	13,260	13,260	13,260
0	1	0	0	307	18,420	36,840	55,260	73,680	18,420	18,420	18,420
1	1	0	0	410	24,600	49,200	73,800	98,400	24,600	24,600	24,600

Features

LED Drive Frequency

Four options for establishing LED drive frequency are provided. These four sources serve as a reference frequency and can be scaled to higher LED drive frequencies via SFM.

1. If a sync signal is present, it is used.
2. If a sync signal is absent, the PWM dimming frequency can be established in one of three ways:
   A. Using the PWM dimming frequency
   B. Using an on-chip precision oscillator at a frequency set by an external resistor
   C. With a external crystal

Choices A, B, and C are selected by configuring the FREF pin. On the demo board, FREF is configured via the f_{REF} switches.

The frequencies of the four sources may be scaled using the Sync Frequency Multiplier (SFM) control. Eleven SFM values are available, ranging from 1 to 410.

Fault Handling

Two new, more effective approaches to handling faults are introduced in the HV9957, in particular to LED faults. These new approaches are temperature-triggered protection for LED faults, and an 'outlier' method to determine which string to disable. LED faults may be categorized three ways.

Open LED: The LED conducts no current. Open string.

Partially open LED: The LED conducts, but at a higher voltage than normal. Zener-bypassed LEDs are in this category. 'Long' string.

Shorted LED: The LED conducts, but with a near-zero voltage. 'Short' string.

Temperature-triggered Fault Protection

A short or long string results in higher than normal voltage across one or more output channels, causing higher power dissipation in the HV9957. Additional losses are incurred in the boost switch, as the increased boost voltage represents a higher load.

If the die temperature remains less than 130°C, no action is taken. However, if die temperature exceeds 130°C, fault protection is activated and faulty channels are disabled one-by-one until OTP stops tripping. This approach avoids turning off strings unnecessarily. If the LEDs are interleaved and diffused, extinguished LEDs may not be apparent, whereas an entire unlit string will most likely be noticeable.

Once OTP activates, an 'outlier' method is used to identify the faulty string(s).

Outlier Faulty String Detection

Two problems exist with conventional LED fault protection.

SLP vs OVP

An open string is normally detected when boost converter OVP trips and those channels with 0V across them are identified as having open strings and are disabled.

A short string is normally identified when channel voltage exceeds a threshold. (SLP)

When the LED driver is enabled, boost voltage ramps up. With an open string, the voltage continues beyond normal, impressing higher than normal voltages across the good channels. If this higher voltage trips SLP before OVP, a good string will be disabled, leaving the open string enabled. OVP repeatedly trips, disabling all the strings.

Usually the solution is to set V_{SLP} to a high voltage that may offer little protection.

Short/Long String Discrimination

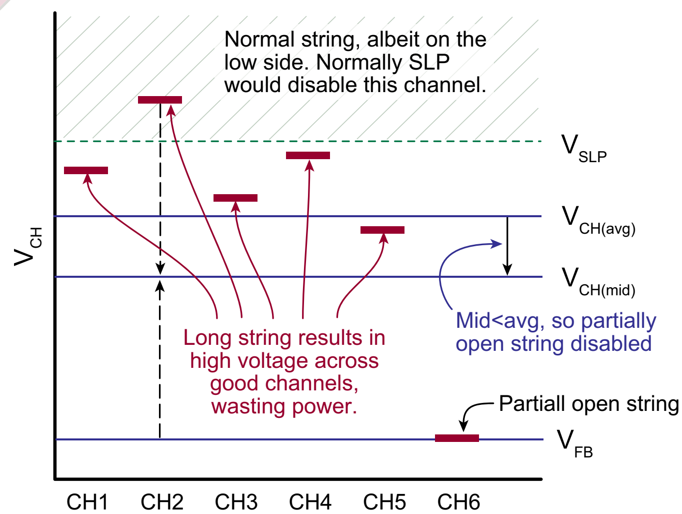
A long string causes higher than normal channel voltages on the remaining good channels. This can result in SLP tripping, disabling the wrong string.

Simultaneous short and long strings complicate things even more. Given the choice between disabling the long string or the short string, disabling the long string is favored. The reason is twofold. First, a long string causes higher driver dissipation than a short string since the long string causes the other five channels to have excessive voltage drop (more dissipation), while a short string results in only the affected channel's voltage being high. Secondly, a long string is usually caused by open LEDs with Zener bypass. Power is lost in these Zeners, resulting in inefficient overall operation. On the other hand, a short string wastes no power in the LED matrix.

Solution

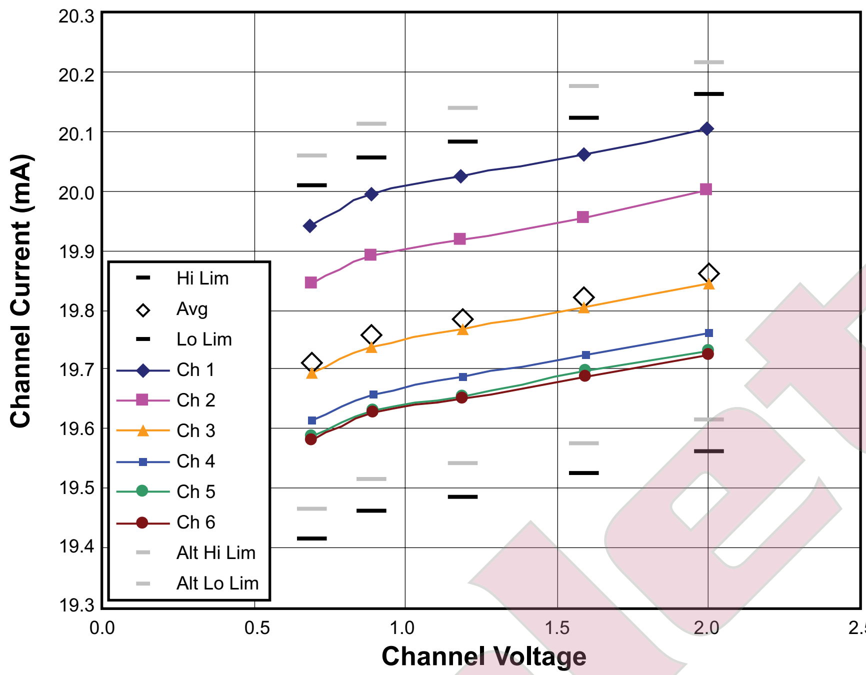
The outlier approach solves these problems by identifying the channel with a voltage furthest from the average (the outlier) and flagging it as having the faulty string. In the event of simultaneous short and long strings, the built-in bias favors disabling the long string. The outlier circuit is triggered by OTP, only disabling faulty strings when absolutely necessary.

Outlier Method

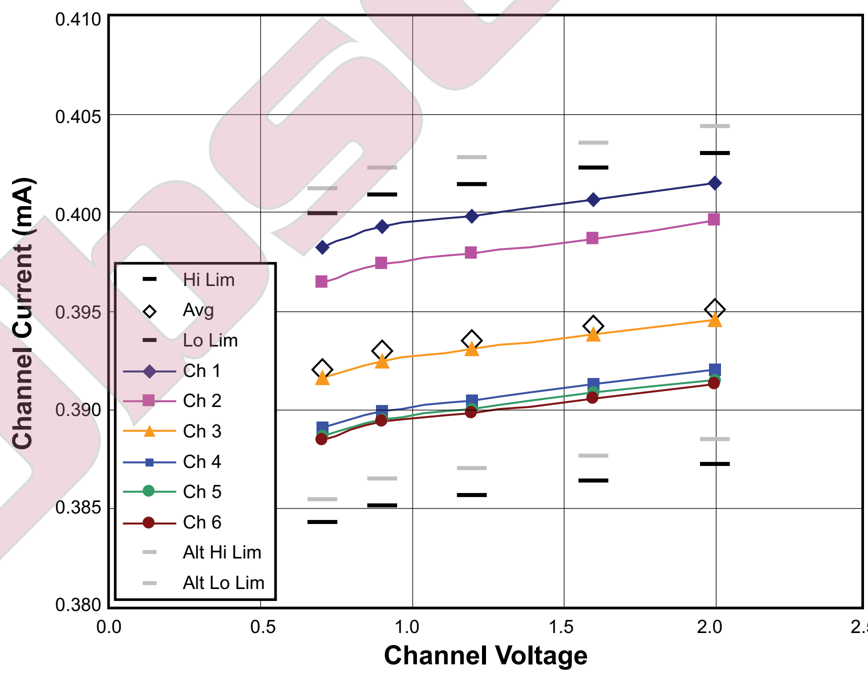


Performance

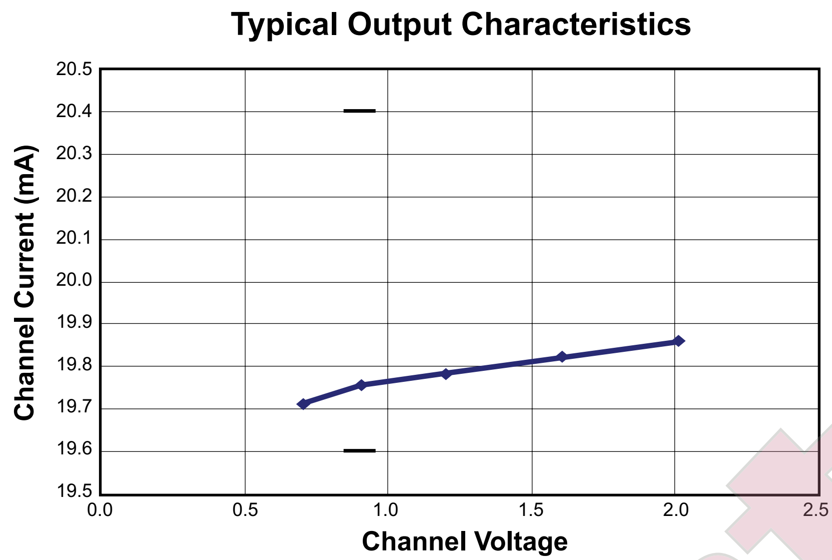
Output Current at 100% PWM Brightness

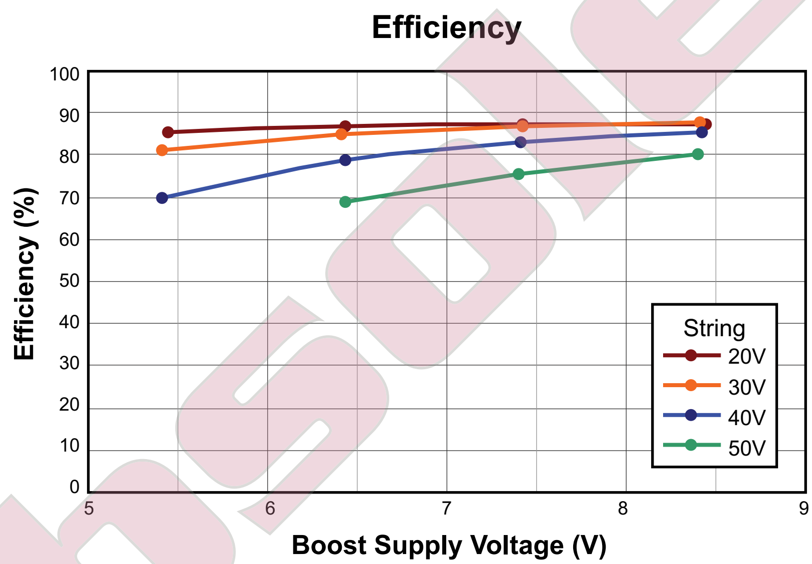


Output Current at 2% PWM Brightness



Channel matching is defined as the deviation from the six channel average, with the limits shown on the graph as black bars. The grey limit bars show an alternate definition as the deviation from the midpoint between the max and min.





Absolute accuracy is defined as the deviation of the six channel average current from the specified nominal current and are shown as black bars.

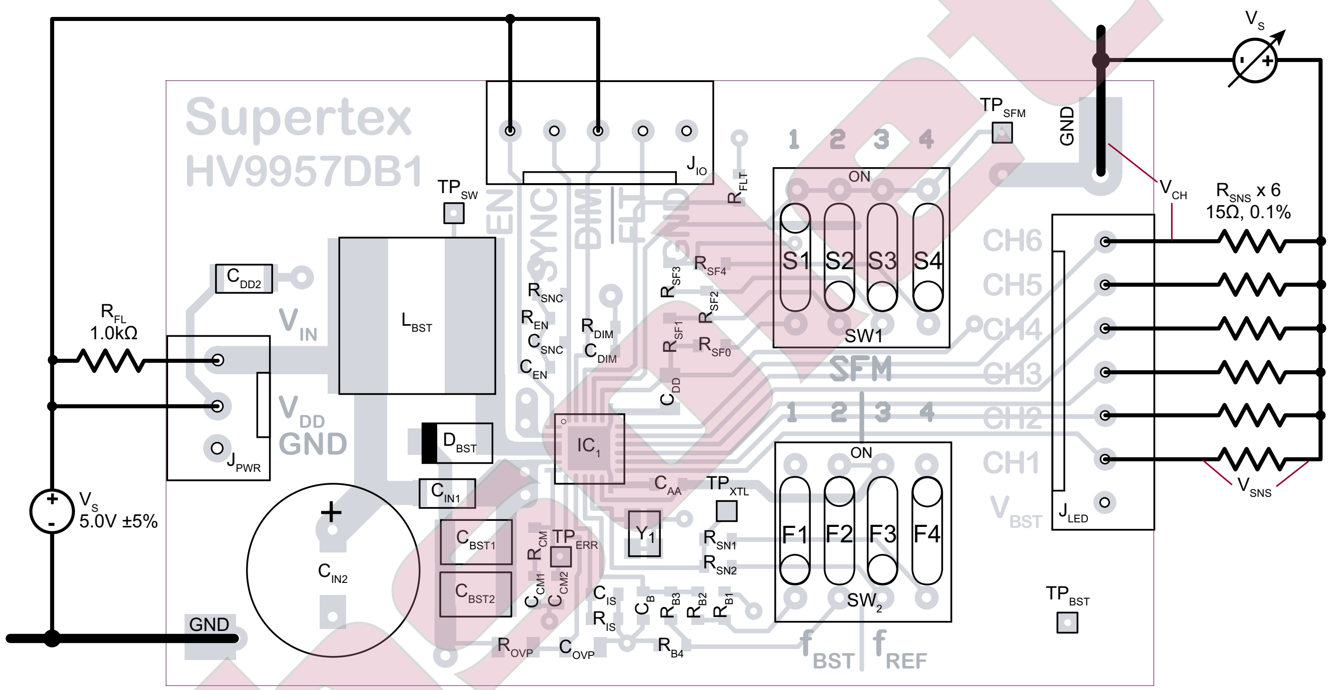
Measurement Methods

Channel Matching

Manufacturers specify channel matching and absolute accuracy in several different ways. Supertex adopts the common description of statistically distributed variables by using mean and standard deviation. Absolute current accuracy is defined as the six channel average current. Channel matching is the maximum deviation from the average. An alternate channel matching definition based on the deviation from the midpoint is also provided.

To remove the effects of string-to-string voltage variations (which are not a property of the driver), channel matching is measured with equal voltages across each channel. To accommodate channel-to-channel voltage variations, channel current is measured at several channel voltages.

Channel Matching Test Setup



Equations:

Standard Definition

$$\Delta I_{CH} = \frac{I_{CH}}{\frac{1}{N_{CH}} \cdot \sum_{n=1}^{N_{CH}} I_n}$$

Alternate Definition

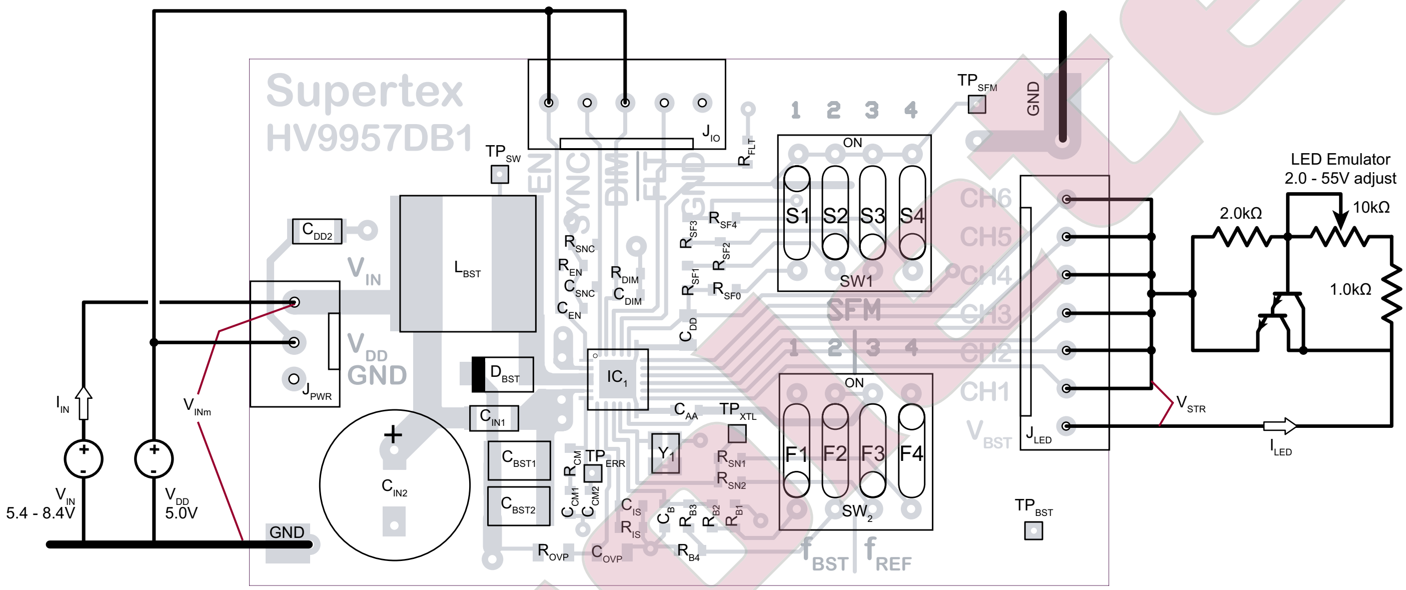
$$\Delta I_{CH} = \frac{I_{CH}}{1/2(I_{MIN} + I_{MAX})}$$

Efficiency

To eliminate losses associated with string-to-string voltage variations (which are not a property of the driver), equal voltages were applied to each channel by connecting all the channels together and loaded with an adjustable-voltage LED emulator.

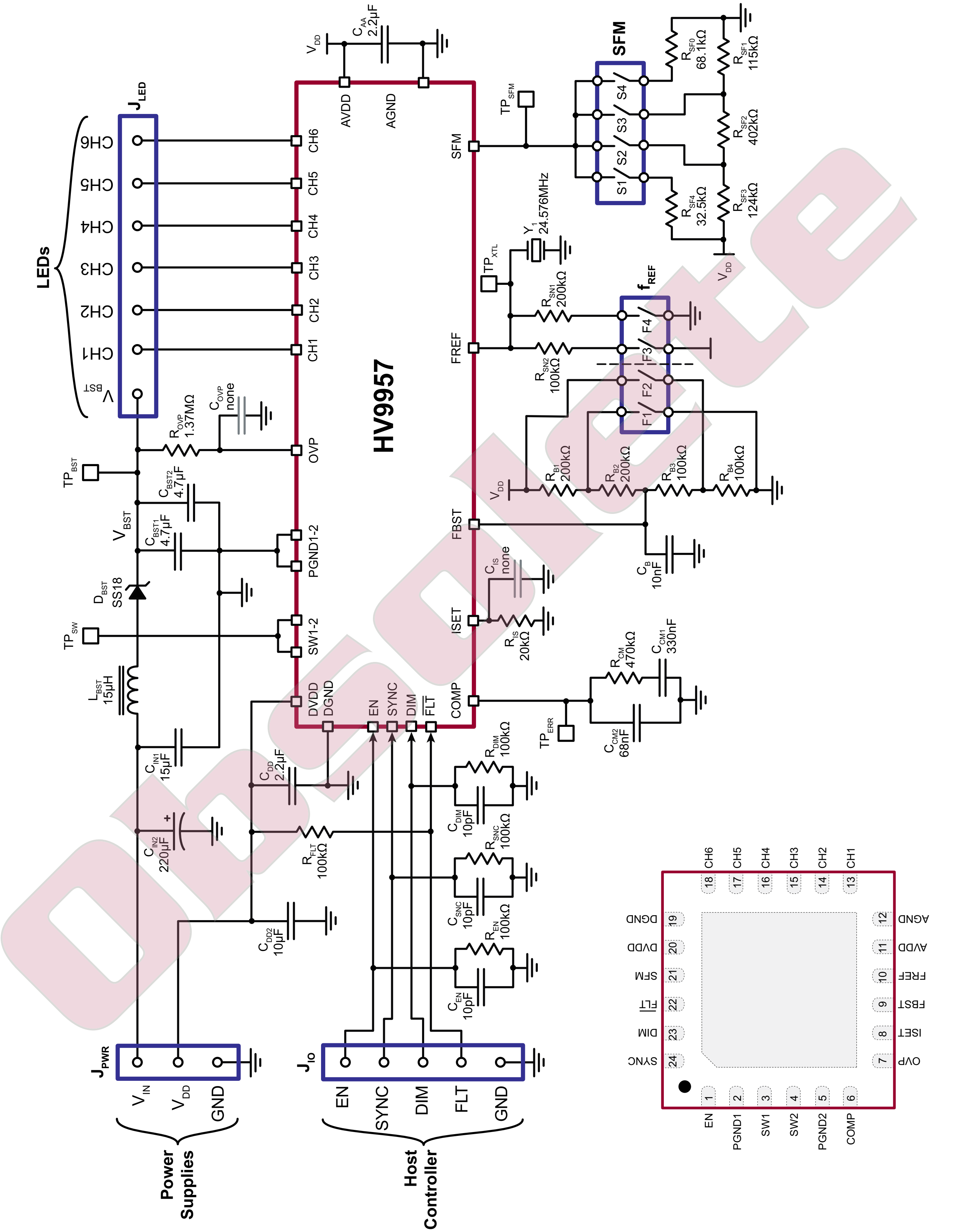
The voltage drop across the I_{LED} current meter is considered part of the load.

Efficiency Test Setup



Equation: $$\eta = \frac{V_{STR} \bullet I_{LED}}{V_{IN} \bullet I_{IN}}$$

Circuit Schematic



Bill of Materials

Desig	Description	Value	Tol	Rating	Pkg	Mfg
R_{FLT}	Resistor	100kΩ	5%	—	0603	any
R_{EN}	Resistor	100kΩ	5%	—	0603	any
R_{SN}	Resistor	100kΩ	5%	—	0603	any
R_{DIM}	Resistor	100kΩ	5%	—	0603	any
R_{OVP}	Resistor	1.37MΩ	1%	60V	0805	any
R_{CM}	Resistor	470Ω	1%	—	0603	any
R_{ISET}	Resistor	20.0kΩ	1%	—	0603	any
R_{B1-2}	Resistor	200kΩ	1%	—	0603	any
R_{B3-4}	Resistor	100kΩ	1%	—	0603	any
R_{SN2}	Resistor	73.2kΩ	1%	—	0603	any
R_{SN1}	Resistor	200.0kΩ	0.1%	—	0603	any
R_{SF0}	Resistor	68.1kΩ	1%	—	0603	any
R_{SF1}	Resistor	115kΩ	1%	—	0603	any
R_{SF2}	Resistor	402kΩ	1%	—	0603	any
R_{SF3}	Resistor	124kΩ	1%	—	0603	any
R_{SF4}	Resistor	82.5kΩ	1%	—	0603	any
C_{IN1}	Capacitor, ceramic, X7R or X5R	4.7µF	20%	16V	1206	any
C_{IN2}	Capacitor, aluminum	330µF	20%	16V	5mm lead spc 10mm dia 12mm high	any
C_{BST1-2}	Capacitor, ceramic, X7R or X5R	4.7µF	20%	63V	1210	any
C_{OVP}	not installed	-	-	-	-	-
C_{DD}	Capacitor, ceramic, X7R or X5R	2.2µF	20%	10V	0805	any
C_{DD2}	Capacitor, ceramic, X7R or X5R	10µF	20%	10V	1206	any
C_{AA}	Capacitor, ceramic, X7R or X5R	220nF	20%	10V	0603	any
C_{EN}	Capacitor, ceramic, X7R or X5R	10pF	20%	10V	0603	any
C_{SYN}	Capacitor, ceramic, X7R or X5R	10pF	20%	10V	0603	any
C_{DIM}	Capacitor, ceramic, X7R or X5R	10pF	20%	10V	0603	any
C_{CM1}	Capacitor, ceramic, X7R or X5R	330nF	20%	10V	0603	any
C_{CM2}	Capacitor, ceramic, X7R or X5R	68nF	20%	10V	0603	any
C_{IS}	Not installed	-	-	-	-	-
C_B	Capacitor, ceramic, X7R or X5R	1nF	20%	10V	0603	any
L_{BST}	Inductor, DR1030 series	15µH	20%	2.5A	$9mm^2$ or less	-
D_{BST}	Diode, Schottky	SS18-TP	-	80V, 1A	SMA	any
Y1	Crystal NX2520SA series	24.576MHz	-	-	special	NDK
IC_1	LED driver	HV9957	-	-	QFN	Supertex

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