DESCRIPTION

PT16978 is three-channel LED driver includes a unique thermal management design to reduce temperature rising on the device. The device is a linear driver directly powered by automotive batteries with large voltage variations to output full current loads up to 150 mA per channel. It includes analog and PWM dimming control, independent PWM dimming for each channel.

External shunt resistors are leveraged to share output current and dissipate power out of the driver. The PT16978 also drives LED units and off-board brightness binning resistors to simplify the manufacturing process and lower whole system cost.

Its full-diagnostic capabilities include LED open, LED short-to-GND circuit and single LED short circuit detection.

The device is available in a HTSSOP20 package, and the operating junction temperature range is –40°C to 150°C.

APPLICATIONS

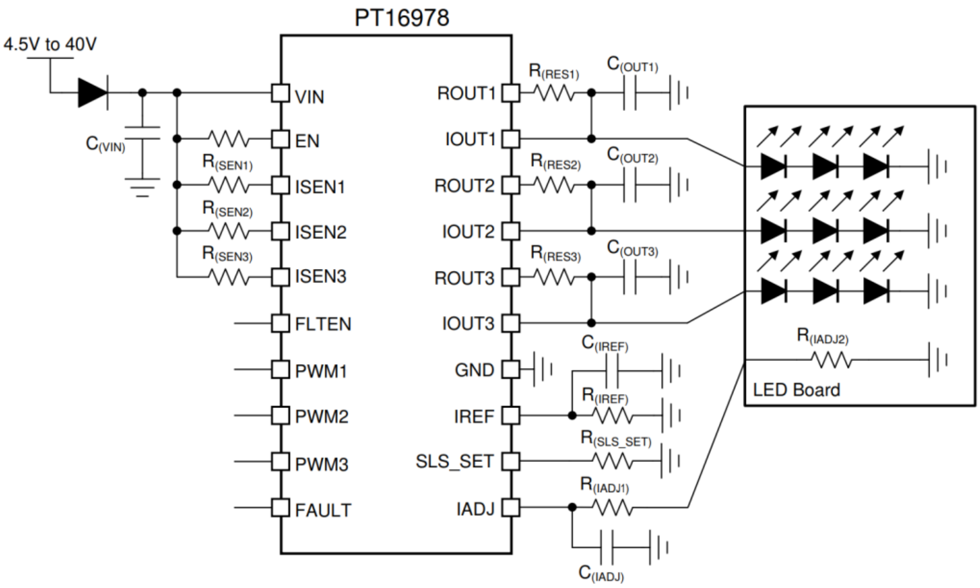
- Rear Combination Light (RCL)
- Position Light
- Turn Light
- Stop or Tail Light
- Fog Light
- General linear LED Light

FEATURES

- Automotive AEC-Q100, Grade 1 (-40℃~+125℃) Qualified
- Input voltage range: 5 V–40 V
- Low supply current in fault mode
- Single resistor set for output current
- - Max. Current: 150 mA per Channel
- - Device Accuracy: ±4%
- - Max. Current: 450 mA in parallel operation mode
- Parallel outputs for higher current using multiple ICs or multiple channels of a single IC
- Low dropout voltage: 600mV@150mA per channel
- Independent PWM dimming per channel
- Thermal sharing by external shunt resistor
- Support off-board brightness binning resistor
- Support external NTC for current derating
- Open and Shorted LED Detection with Deglitch Timer
- Single LED short-circuit detection with auto recovery

Fault bus configurable as either one-fails–all-fail or only-failed-channel off (N-1) Diagnostic enable with adjustable threshold

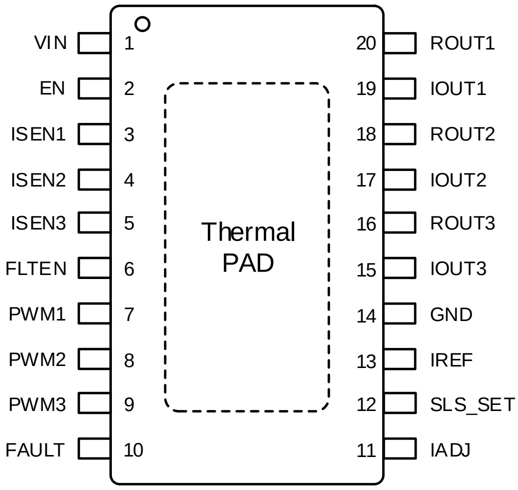
TYPICAL APPLICATION



1 ORDER INFORMATION

Part Number	Package	Top Code
PT16978	HTSSOP 20pins	PT16978

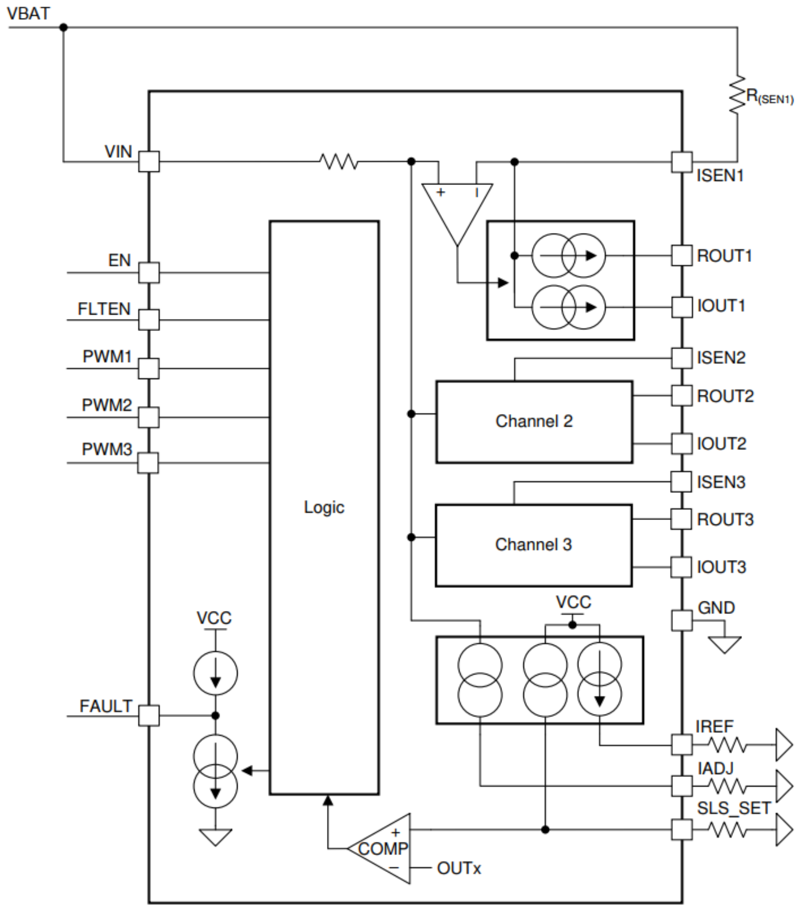
2 PIN CONFIGURATION



3 PIN DESCRIPTION

PIN Name	PIN No.	I/O	DESCRIPTION
VIN	1	--	Supply voltage input.
EN	2	I	Enable and shut down. Setting input signal to logic-low, turn off the device.
ISEN1	3	I	Current input for channel x.
ISEN2	4	I	
ISEN3	5	I	
FLTEN	6	I	Enable pin for LED open-circuit detection and single LED short detection. Pull down the FLTEN pin to disable the LED open-circuit and single LED short detection to avoid false open and single LED short diagnostics during low-dropout operation.
PWM1	7	I	PWM input and channel ON or OFF. Tie to GND if this channel is not used.
PWM2	8	I	
PWM3	9	I	
FAULT	10	I/O	Fault output, support one-fails–all-fail fault bus.
IADJ	11	O	Resistor programmable voltage reference pin for LED binning resistor or NTC resistor.
SLS_SET	12	O	Resistor programmable voltage reference pin for single LED short threshold.
IREF	13	O	Current reference pin. A 12.3-kΩ resistor is recommended to be connected between IREF pin and ground.
GND	14	--	Power Ground.
IOUT3	15	O	Current output for channel 3. A 10-nF capacitor is recommended between the pin to GND.
ROUT3	16	O	Current output for channel 3 with external thermal resistor.
IOUT2	17	O	Current output for channel 2. A 10-nF capacitor is recommended between the pin to GND.
ROUT2	18	O	Current output for channel 2 with external thermal resistor.
IOUT1	19	O	Current output for channel 1. A 10-nF capacitor is recommended between the pin to GND.
ROUT1	20	O	Current output for channel 1 with external thermal resistor.

4 FUNCTIONAL BLOCK DIAGRAM



5 FUNCTION DESCRIPTION

5.1 OVERVIEW

PT16978 is three-channel LED driver includes a unique thermal management design to reduce temperature rising on the device. The device is a linear driver directly powered by automotive batteries with large voltage variations to output full current loads up to 150 mA per channel. The current output at each channel can be independently set by external $R_{(SEN)}$ resistors. Current flows from the supply through the $R_{(SENx)}$ resistor into the integrated current regulation circuit and to the LEDs through IOUTx pin and ROUTx pin. All three-channel current is configurable by an external resistor connected to the IADJ pin. Either a NTC resistor for LED temperature monitor or a LED brightness binning resistor can be connected to IADJ pin in same board or off-board. The device supports both supply control and EN/PWM control to turn LED ON/OFF. The LED brightness is also adjustable by voltage duty cycle applied on either SUPPLY or EN/PWM with frequency above 100 Hz.

The PT16978 provides full diagnostics to keep the system operating reliably including LED open/short circuit detection, single LED short circuit detection, supply POR and thermal shutdown protection. The PT16978 can be used with other devices (PT16977) together to achieve one-fails-all-fail protection by tying all FAULT pins together as a fault bus.

5.2 POWER-ON RESET

PT16978 has an internal power-on-reset (POR) function. When power is applied to the VIN pin, the internal POR circuit holds the device in reset state until V(VIN) is above $V_{(POR\_rising)}$.

5.3 SUPPLY CURRENT IN FAULT MODE

PT16978 consumes minimal quiescent current, $I_{(Fault)}$, into VIN when the FAULT pin is externally pulled LOW. At the same time, the device shuts down all three output drivers, IREF and IADJ.

If device detects a fault, it pulls down the FAULT pin by an internal constant current, $I_{(fault\_pulldown)}$ as a fault indication to the fault bus.

5.4 POWER SUPPLY (VIN)

PT16978 can support supply control to turn ON and OFF output current. When the voltage applied on the VIN pin is higher than the LED string forward voltage plus needed headroom voltage at required current, and the PWM pin voltage is high, the output current is turned ON and well regulated. However, when the voltage applied on the VIN pin is lower than $V_{(POR\_rising)}$, the output current is turned OFF. With this feature, the power supply voltage in designed pattern can control the output current ON/OFF. The brightness is adjustable if the ON/OFF frequency is fast enough. Because of the high accuracy design of PWM threshold in PT16978, it enables a resistor divider on the PWM pin to set the VIN threshold higher than LED forward voltage plus required headroom voltage as shown in Figure 1. The headroom voltage is basically the summation of $V_{(DROPOUT)}$ and $V_{(CS\_REG)}$. When the voltage on the PWM pin is higher than $V_{IH(PWM)}$, the output current is turned ON. However, when the voltage on the PWM is lower than $V_{IL(PWM)}$, the output current is turned OFF. The VIN threshold voltage can be calculated by using Equation 1.

$$V_{IN\_PWM\_TH} = V_{IH(PWM)} \times (1 + \frac{R_{UPPER}}{R_{LOWER}}) \quad (1)$$

$V_{IH(PWM)}$=1.23(maximum)

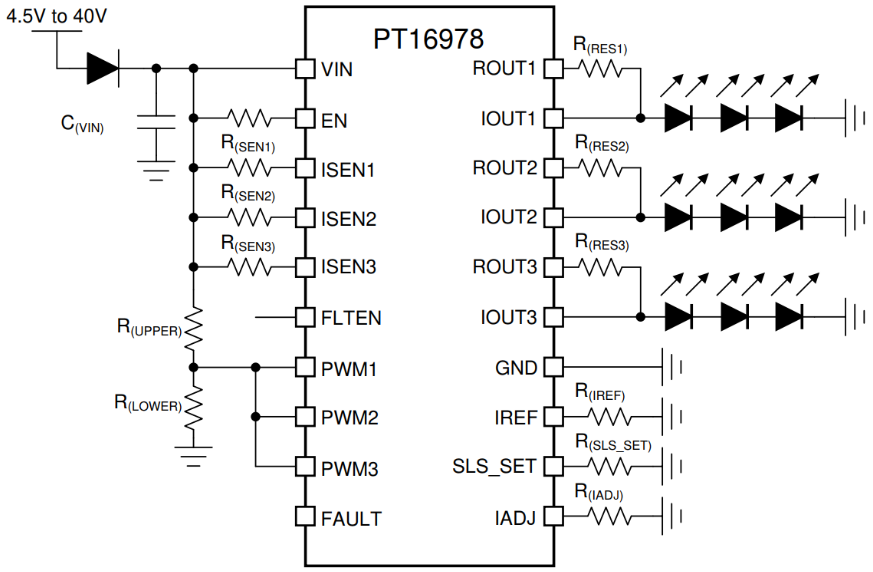


Figure 1 Application Schematic for Supply Control LED Brightness

5.5 ENABLE AND SHUTDOWN (EN)

PT16978 has an enable input. When EN is low, the device is in sleep mode with ultra low quiescent current $I_{(SD)}$. This low current helps to save system-level current consumption in applications where battery voltage directly connects to the device without high-side switches.

5.6 LED CONSTANT-CURRENT OUTPUT AND SETTING

PT16978 is a high-side current driver for driving LEDs. The device controls each output current through regulating the voltage drop on an external high-side current-sense resistor, $R_{(SENx)}$ between VIN and ISENx independently for each channel. An integrated error amplifier drives an internal power transistor to maintain the voltage drop on the current-sense resistor $R_{(SENx)}$ to $V_{(CS\_REG)}$, therefore regulates the current output to target value. When the output current is in regulation, the current value for each channel can be calculated by using Equation 2.

$$I_{INx} = \frac{V_{CS\_REG}}{R_{SENx}} \quad (2)$$

When the supply voltage drops below total LED string forward voltage plus required headroom voltage, the sum of ($V_{(DROP\ OUT)}$) and $V_{(CS\_REG)}$, the PT16978 is not able to deliver enough current output as set by the value of $R_{(SENx)}$, and the voltage across the current-sense resistor $R_{(SENx)}$ is less than $V_{(CS\_REG)}$.

5.7 REFERENCE CURRENT(IREF)

The IREF pin of PT16978 generates a high accuracy and low temperature shift current reference. The calculated result for $I_{(IREF)}$ is 100 µA when $R_{(IREF)}$ is 12.3 kΩ. The $I_{(IREF)}$ can be programmed by external resistor, $R_{(IREF)}$ in the range from 25 µA to 250 µA. The voltage on the IREF pin is regulated to the 1.235 V typically, and the current output on IREF pin can be calculated by using Equation 3.

$$I_{IREF} = \frac{V_{IREF}}{R_{IREF}} \quad (3)$$

The $R_{(IREF)}$ resistor needs to be placed as close as possible to the IREF pin with a 1-nF ceramic capacitor in parallel to achieve the noise immunity. The off-board $R_{(IREF)}$ setup is not allowed due to the concern of reference current instability.

5.8 ANALOG CURRENT CONTROL (IADJ)

PT16978 supports analog constant current control for all three output channels together through adjusting the $V_{(CS\_REG)}$ voltage. As described in Constant-Current Output and Setting (ISENx), the device regulates each channel output current by maintaining the voltage drop on each $R_{(SENx)}$ same to $V_{(CS\_REG)}$. The $V_{(CS\_REG)}$ voltage is adjustable by an external resistor on IADJ pin. The device outputs a constant current, $I_{(IADJ)}$, on the IADJ pin and measures the voltage on the IADJ pin, $V_{(IADJ)}$, to determine the $V_{(CS\_REG)}$. The $I_{(IADJ)}$ current is 10 times of the $I_{(IREF)}$, and the $V_{(IADJ)}$ is multiplied result of $I_{(IADJ)}$ and $R_{(IADJ)}$. The PT16978 internally clamps the $V_{(IADJ)}$ to maximum 2.75 V. The $V_{(CS\_REG)}$ voltage can be calculated
by using Equation 4.

$$V_{CS\_REG} = \frac{I_{IREF} \times R_{IADJ} \times 25}{17} \tag{4}$$

The minimum voltage of $V_{(CS\_REG)}$ is 50 mV typically to maintain the high accurate current output.
The final total output current for each channel can be calculated by using Equation 5 which is combination of Equation 2, Equation 3 and Equation 4.

$$I_{INx} = \frac{V_{IREF} \times R_{IADJ} \times 25}{R_{IREF} \times R_{SENx} \times 17} \tag{5}$$

I_{INx} is in mA unit; $V_{(IREF)}$=1.235V; $R_{(IREF)}$ is in kΩ unit; $R_{(IADJ)}$ and $R_{(SENx)}$ is in Ω unit.
The calculated result for I_{INx} is 151.3mA when $R_{(IREF)}$ is 12kΩ, $R_{(IADJ)}$ is 1000Ω and $R_{(SENx)}$ is 1Ω.

5.9 OFF-BOARD BRIGHTNESS BINNING RESISTOR

With analog current control feature, a LED brightness binning resistor can be connected to IADJ pin to set the output current according to LED brightness bin. The binning resistor can be placed in off-board with LED units. In order to achieve the best performance for the noise rejection, two resistors in serial can be adopted. One resistor is placed as closed as possible to the IADJ pin in the same PCB board with device, and another one real binning resistor is placed in the other PCB board with LED units together.
As Figure 2 illustrated, the $R_{(IADJ1)}$ resistor and $C_{(IADJ)}$ ceramic capacitor need to be placed as close as possible to the IADJ pin for noise decoupling. The off-board $R_{(IADJ2)}$ resistor can be placed in LED board as real binning resistor. It recommends a 10-nF ceramic capacitor for $C_{(IADJ)}$.

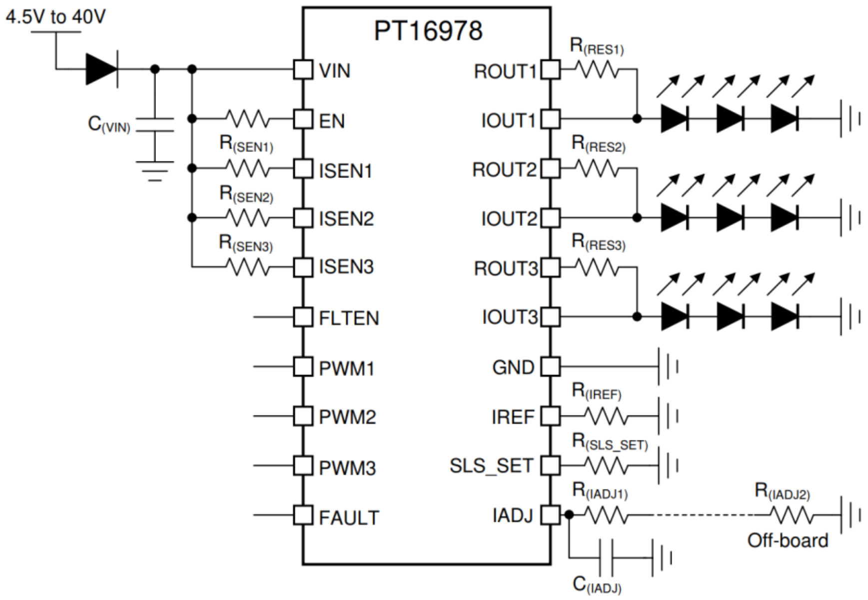


Figure 2 Application Schematic for Off-Board Brightness Binning Resistor

5.10 NTC RESISTOR

The analog current control feature also allows to connect a NTC thermistor on IADJ pin to achieve the LED current derating based on measured PCB board temperature or LED unit temperature. The resistance of NTC thermistor depends on the environment temperature. The resistance of NTC thermistor is decreasing with the temperature rising. It leads to the decreasing of the equivalent resistance of $R_{(IADJ)}$ on IADJ pin and the output current reduction from the calculation based on Equation 2 and Equation 4.

It recommends to connect a resistor network including NTC thermistor to IADJ pin as illustrated in below Figure 3. The resistor value of R1 and R2 work with NTC thermistor to adjust the equivalent resistance curve depending on the temperature to achieve the system required current derating.。

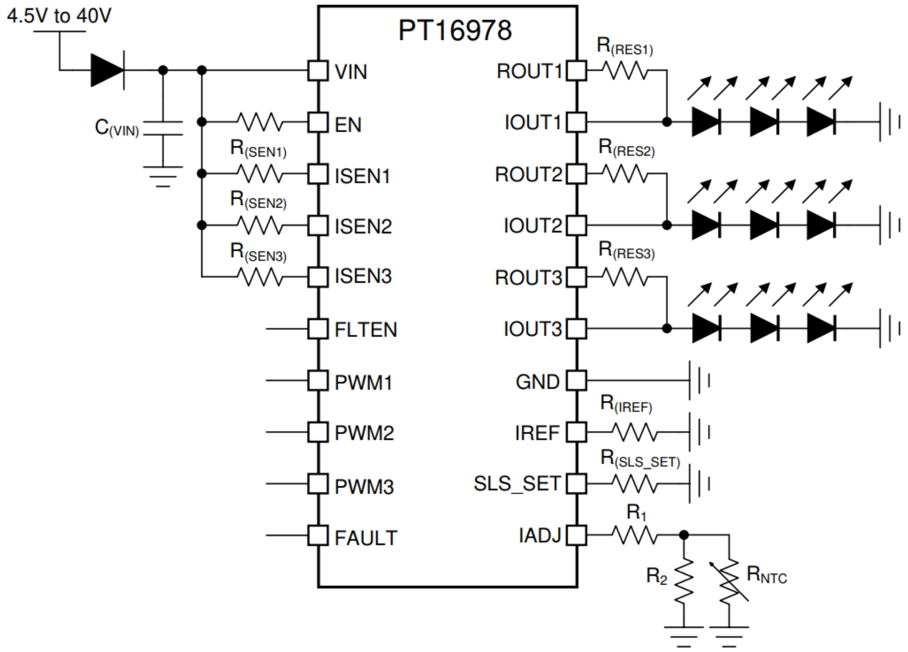


Figure 3 Application Schematic for External NTC Thermistor

5.11 PWM CONTROL (PWMX)

The pulse width modulation (PWM) input of the PT16978 functions as enable for the output current. When the voltage applied on the PWM pin is higher than $V_{IH(PWM)}$, the relevant output current is enabled. When the voltage applied on PWM pin is lower than $V_{IL(PWM)}$, the output current is disabled as well as the diagnostic features. Besides output current enable and disable function, the PWM input of PT16978 also supports adjustment of the average current output for brightness control when the frequency of applied PWM signal is higher than 100 Hz, which is out of visible frequency range of human eyes. It recommends a 200-Hz PWM signal with 1% to 100% duty cycle input for brightness control. Please refer to Figure 4 for typical timing information.

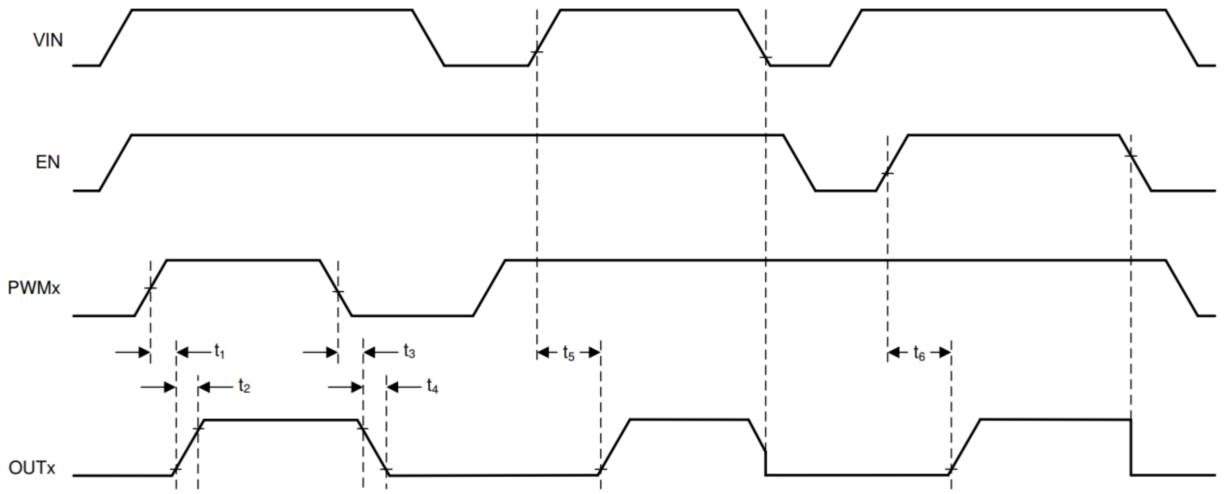


Figure 4 Power On Sequence and PWM Dimming Timing

t_1 - $t_{(PWM\_delay\_rising)}$; t_2 - $t_{(Current\_rising)}$; t_3 - $t_{(PWM\_delay\_falling)}$; t_4 - $t_{(Current\_falling)}$; t_5 – $t_{(VIN\_STARTUP)}$; t_6 – $t_{(EN\_STARTUP)}$

The detailed information and value of each time period in Figure 4 is described in Timing Requirements.

The PT16978 device has three total PWM input pins, PWM1, PWM2 and PWM3, to control each of current output channel independently. PWM1 input controls the output channel1 for both IOUT1 and ROUT1, PWM2 input controls the output channel2 for both IOUT2 and ROUT2, and PWM3 input controls the output channel3 for both IOUT3 and ROUT3.

5.12 THERMAL SHARING RESISTOR

The PT16978 provides two current output paths for each channel. Current flows from the supply through the $R_{(SENx)}$ resistor into the integrated current regulation circuit and to the LEDs through IOUTx pin and ROUTx pin. The current output on both IOUTx pin and ROUTx pin is independently regulated to achieve total required current output. The summed current of IOUTx pin and ROUTx is equal to the current through the $R_{(SENx)}$ resistor in the channel. The IOUTx connects to anode of LEDs load in serial directly, however ROUTx connects to the LEDs through an external resistor to share part of the power dissipation and reduce the thermal accumulation in the device.

The integrated independent current regulation in PT16978 dynamically adjusts the output current on both IOUTx pin and ROUTx output to maintain the stable summed current for LED. The device always regulates the current output to the ROUTx pin as much as possible until the ROUTx current path is saturated, and the rest of required current is regulated from the IOUTx. As a result, the most of the current to LED outputs through the ROUTx pin when the voltage dropout is relatively high between VIN and LED required total forward voltage.

In the opposite case, the most of the current to LED outputs through the IOUTx pin when the voltage headroom is relatively low between VIN and LED required forward voltage. Figure 5 and Figure 6 shows the curve of current and power dissipation distributor depending on supply voltage when $R_{(ROUTx)}$ is 68.5 Ω.

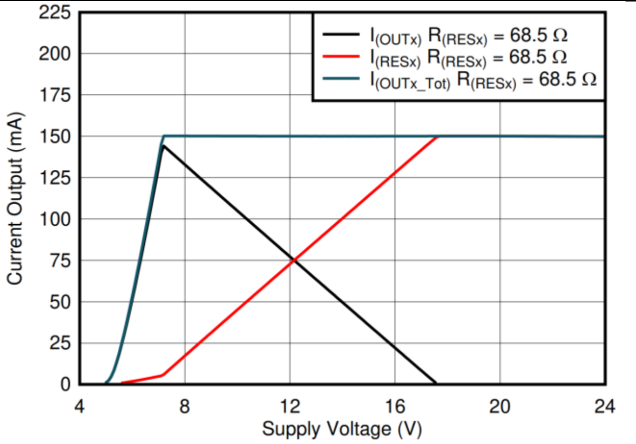


Figure 5 Output Current Distribution vs Supply Voltage

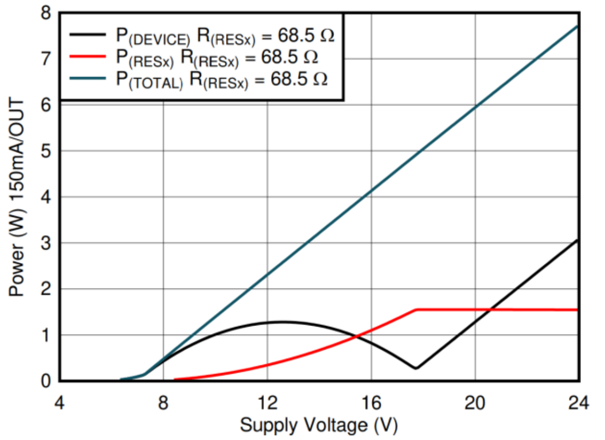


Figure 6 Power Dissipation vs Supply Voltage

5.13 DIAGNOSTICS

The device is able to detect and protect fault from LED-string short-to-GND, LED-string open-circuit, single LED short-circuit and junction over-temperature scenarios. It also supports one-fails–all-fail fault bus design that can flexibly fit different regulatory requirements.

5.13.1 IREF SHORT-TO-GND DETECTION

The PT16978 has IREF short-to-GND detection through monitoring the voltage on the IREF pin. The IREF pin short-to-GND fault is reported by constantly pulling down the FAULT pin, if the IREF pin voltage, $V_{(IREF)}$ is lower than $V_{(IREF\_SHORT\_th)}$ for longer than the deglitch time of $t_{(IREF\_deg)}$. The current for all output channels and IADJ pin are turned off and the current out of IREF pin is clamped to $I_{(IREF\_ST\_Clamp)}$ when IREF pin short-to-GND fault is detected.
The PT16978 recovers to normal operating if the $V_{(IREF)}$ voltage rises up over $V_{(IREF\_SHORT\_th)}$.

5.13.2 IREF OPEN DETECTION

The PT16978 has IREF open detection through monitoring the current through the IREF pin. The IREF pin open fault is reported by constantly pulling down the FAULT pin, when the current through IREF pin, $I_{(IREF)}$ is lower than $I_{(IREF\_SHORT\_th)}$ for longer than the deglitch time of $t_{(IREF\_deg)}$. The current for all output channels and IADJ pin are turned off when IREF pin open fault is detected.
The PT16978 recovers to normal operating if the $I_{(IREF)}$ current rises up over $I_{(IREF\_SHORT\_th)}$.

5.13.3 LED SHORT-TO-GND DETECTION

PT16978 has LED short-to-GND detection. The LED short-to-GND detection monitors the output voltage when the output current is enabled. Once a short-to-GND LED failure is detected, the device turns off the faulty channel and retries automatically, regardless of the state of the PWM input. When the retry mechanism detects the removal of the LED short-to-GND fault, the device resumes to normal operation.
PT16978 monitors the $V_{(IOUTx)}$ voltage and $V_{(ROUTx)}$ voltage of each channel and compares it with the internal reference voltage to detect a short-to-GND failure. When $V_{(IOUTx)}$ or $V_{(ROUTx)}$ voltage falls below $V_{(SG\_th\_flaging)}$ longer than the deglitch time of $t_{(SG\_deg)}$, the device asserts the short-to-GND fault and pulls low the FAULT pin. During the deglitch time period, if $V_{(IOUTx)}$ and $V_{(ROUTx)}$ rises above $V_{(SG\_th\_ring)}$, the timer is reset.
Once the PT16978 has asserted a short-to-GND fault, the device turns off the faulty output channel and retries automatically with a small current. During retrying the device sources a small current $I_{(Retry)}$ from VIN to OUT to pull up the LED loads continuously. Once auto-retry detects output voltage rising above $V_{(SG\_th\_ring)}$, it clears the short-to-GND fault and resumes to normal operation. Figure 7 illustrates the timing for LED short-circuit detection, protection, retry and recovery.

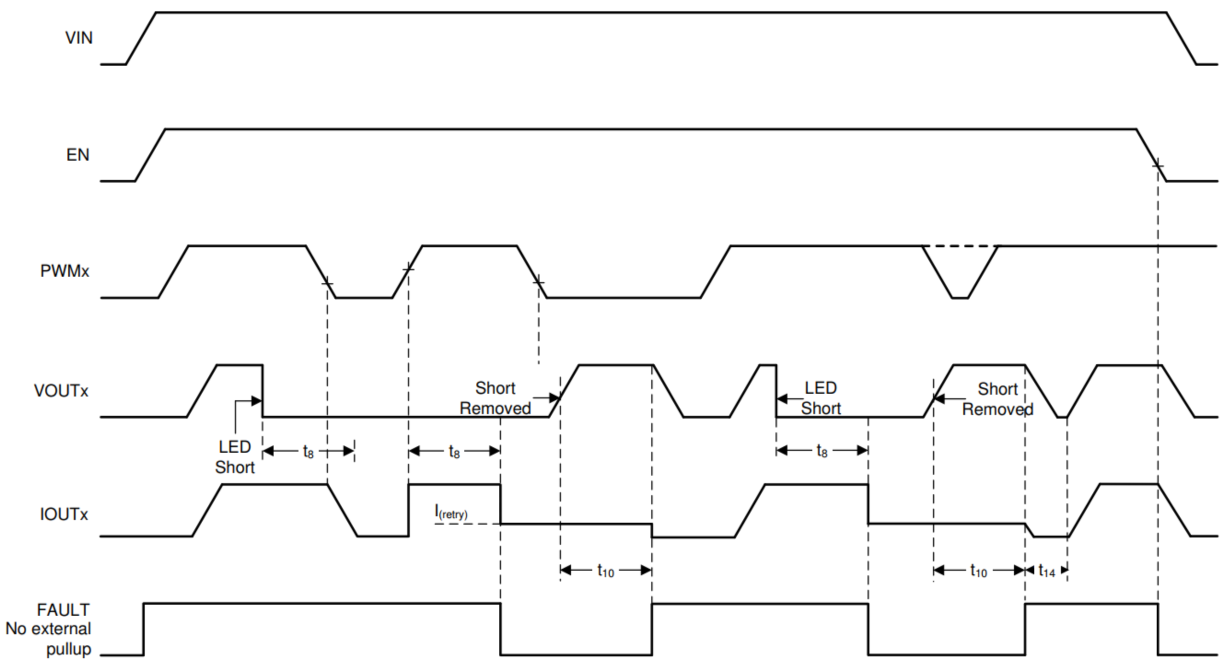


Figure 7 LED Short-to-GND Detection and Recovery Timing Diagram

t_8 – $t_{(SG\_deg)}$; t_{10} - $t_{(Recover\_deg)}$; t_{14} - $t_{(FAULT\_recovery)}$;

The detailed information and value of each time period in Figure 7 is described in Timing Requirements.

5.13.4 LED OPEN-CIRCUIT DETECTION

PT16978 device has LED open-circuit detection. The LED open-circuit detection monitors the output voltage when the current output is enabled. The LED open-circuit detection is only enabled when DIAGEN is HIGH. A short-to-battery fault is also detected and recognized as an LED open-circuit fault.

PT16978 monitors dropout-voltage differences between the ISEN and IOUT pins for each LED channel when PWM is HIGH. The voltage difference $V_{(ISEN)} - V_{(IOUTx)}$ is compared with the internal reference voltage $V_{(OPEN\_th\_rising)}$ to detect LED open-circuit incident. When $V_{(IOUTx)}$ rises causing $V_{(ISEN)} - V_{(IOUTx)}$ less than the $V_{(OPEN\_th\_rising)}$ voltage and lasts longer the deglitch time of $t_{(OPEN\_deg)}$, the device asserts an open-circuit fault. Once a LED open-circuit failure is detected, the internal constant-current sink pulls down the FAULT pin voltage. During the deglitch time period, when $V_{(IOUTx)}$ falls and makes $V_{(ISEN)} - V_{(IOUTx)}$ larger than $V_{(OPEN\_th\_rising)}$, the deglitch timer is reset.

PT16978 shuts down the output current regulation for the faulty channel after LED open-circuit fault is detected. The device sources a small current $I_{(Retry)}$ from VIN to IOUT when FLTEN input is logic High. Once the fault condition is removed, the device resumes normal operation and releases the FAULT pin. Figure 8 illustrates the timing for LED open-circuit detection, protection, retry and recovery.

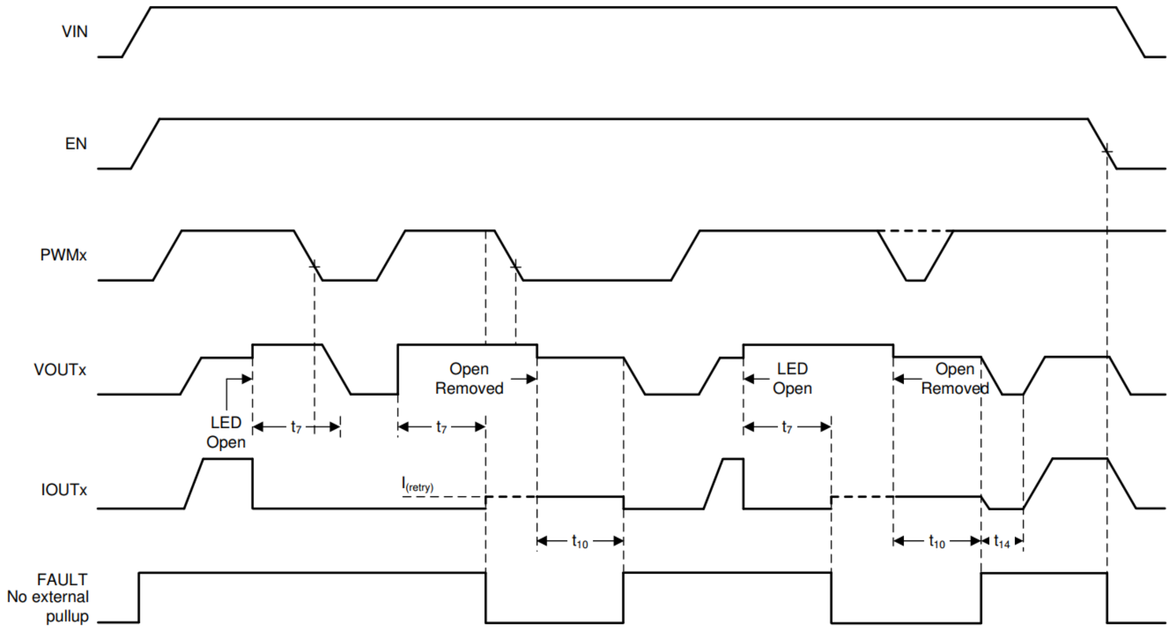


Figure 8 LED Open-Circuit Detection and Recovery Timing Diagram

T_7 – $t_{(OPEN\_deg)}$； t_{10} - $t_{(Recover\_deg)}$； t_{14} - $t_{(FAULT\_recovery)}$；

The detailed information and value of each time period in Figure 8 is described in Timing Requirements.

5.13.5 SINGLE LED SHORT-CIRCUIT DETECTION

The PT16978 has single LED short-circuit detection. The single LED short-circuit detection monitors the output voltage when the output current is enabled. Once a single LED short-circuit failure is detected, the device turns off the faulty channel and retries automatically, regardless of the state of the PWM input. If the retry mechanism detects the removal of the single LED short-circuit fault, the device resumes to normal operation.

The PT16978 monitors the $V_{(IOUTx)}$ voltage of each channel and internally compares the scale down voltage of $V_{(IOUTx)}$ with an external resistor programmable reference voltage on SLS_SET to detect a single LED short-circuit failure. When the voltage of $V_{(IOUTx)}$ falls below $V_{(SLS\_th\_falling)}$ longer than the deglitch time of $t_{(SLS\_deg)}$, the device asserts the single LED short-circuit fault and pulls low the FAULT pin. During the deglitch time period, if the scale down voltage of $V_{(IOUTx)}$ rises above $V_{(SLS\_th\_rising)}$, the timer is reset.

Once the PT16978 has asserted a single LED short-circuit fault, the device turns off the faulty output channel and retries automatically. During retrying the device sources full current from VIN to IOUT to pull up the LED loads every 10 ms for 300-µs period when the PWM input is logic high for the faulty channel. Once auto-retry detects the voltage of $V_{(IOUTx)}$) rising above $V_{(SLS\_th\_rising)}$, it clears the single LED short-circuit fault and resumes to normal operation. The $V_{(SLS\_th\_rising)}$ is 2.5% higher the $V_{(SLS\_th\_falling)}$. The scale down ratio for $V_{(IOUTx)}$ is $N_{(O}$UT). Figure 9 describes internal diagram for single LED short-circuit detection circuit. And the $V_{(SLS\_th\_falling)}$ threshold voltage for single LED short-circuit is calculated by using Equation 6.

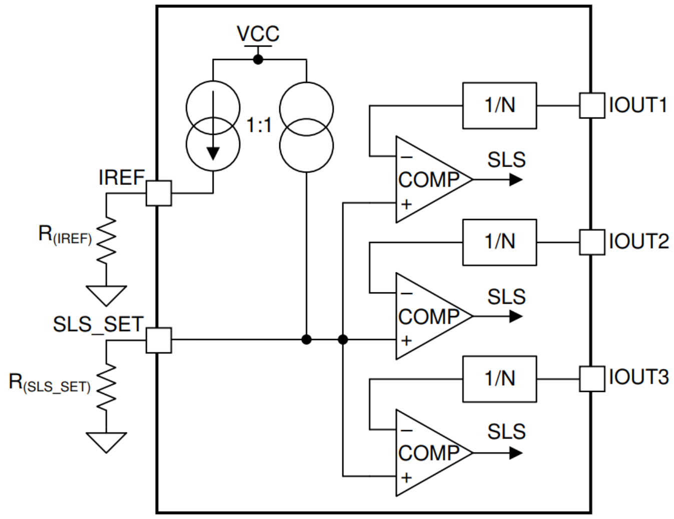


Figure 9 Single LED Short-Circuit Detection Block Diagram

$$V_{\text{SLS\_th\_falling}} = \frac{V_{IREF} \times R_{SLS\_SET} \times N_{SLS\_SET} \times N_{OUT}}{R_{IREF}} \quad (6)$$

$V_{(IREF)}$ = 1.235V (typical)
$R_{(IREF)}$ = 12.3 kΩ
$R_{(SLS\_SET)}$ is in kΩ unit
$N_{(OUT)}$ = 4 (typical)
$N_{(SLS\_SET)}$ =1 (typical)
The calculated result for $V_{(SLS\_th\_falling)}$ is 5.34 V when $R_{(IREF)}$ is 12.3 kΩ and $R_{(SLS\_SET)}$ is 13.3 kΩ.
Figure 10 illustrates the timing for single-LED short-circuit detection, protection, retry and recovery.

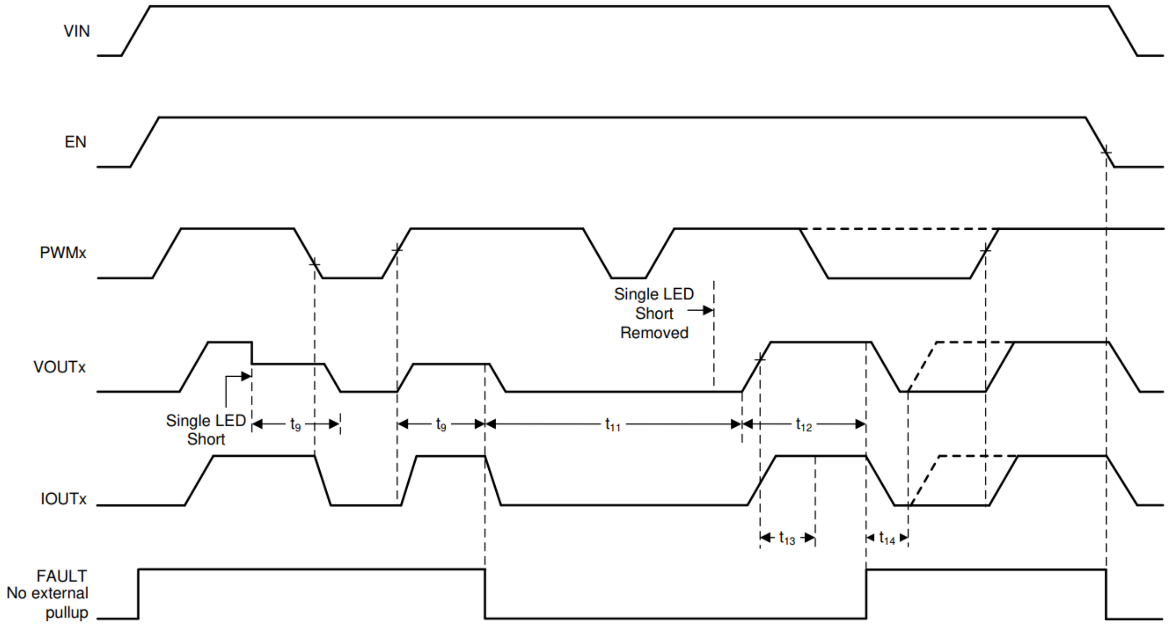


Figure 10 Single LED Short-Circuit Detection and Recovery Timing Diagram

t_9 - $t_{(SLS\_deg)}$； t_{11} - $t_{(SLS\_retry\_interval)}$； t_{12} - $t_{(SLS\_retry\_period)}$； t_{13}- $t_{(SLS\_retry\_deg)}$； t_{14} - $t_{(FAULT\_recovery)}$；
The detail information and value of each time period in Figure 10 is described in Timing Requirements.

5.13.6 LED OPEN-CIRCUIT AND SINGLE LED SHORT-CIRCUIT DETECTION ENABLE

PT16978 supports the FLTEN pin with an accurate threshold to disable the LED open-circuit and single LED short-circuit diagnostic functions. The FLTEN pin can be used to enable or disable LED open-circuit detection and single LED short-circuit detection based on VIN pin voltage sensed by an external resistor divider as illustrated in Figure 11. When the voltage applied on FLTEN pin is higher than the threshold $V_{IH(FLTEN)}$, the device enables LED open-circuit and single LED short-circuit diagnosis.
When the voltage of FLTEN pin is lower than the threshold $V_{IL(FLTEN)}$, the device disables LED open-circuit and single LED short-circuit detection.

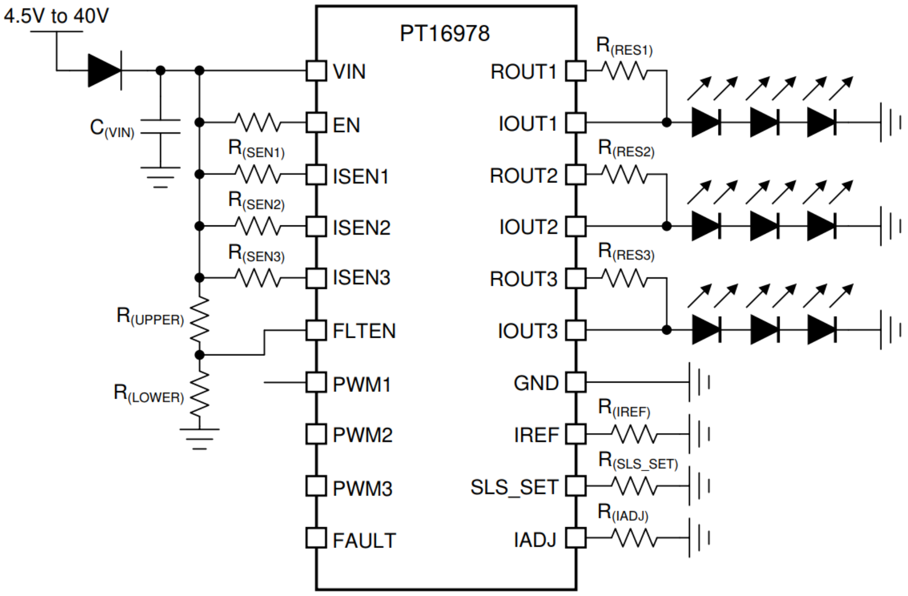


Figure 11 Application Schematic for FLTEN

Only LED open-circuit detection and single LED short-circuit detection can be disabled by pulling down the FLTEN pin. The LED short-to-GND detection and over-temperature protection cannot be turned off by pulling down the FLTEN pin. The VIN threshold voltage can be calculated by using Equation 7.

$$V_{\mathrm{FLTEN\_th\_falling}} = V_{\mathrm{IL(FLTEN)}} \times (1 + \frac{R_{(UPPER)}}{R_{(LOWER)}}) \quad (7)$$

$V_{IL(FLTEN)}$= 1.045V (minimum)

5.13.7 LOW DROPOUT OPERATION

When the supply voltage drops below LED string total forward voltage plus headroom voltage at required current, the PT16978 operates in low-dropout conditions to deliver current output as close as possible to target value. The actual current output is less than preset value due to insufficient headroom voltage for power transistor. As a result, the voltage across the sense resistor fails to reach the regulation target. The headroom voltage is the summation of $V_{(DROPOUT)}$ and $V_{(CS\_REG)}$.
If the PT16978 is designed to operate in low-dropout condition, the open-circuit diagnostics and single LED short-circuit detection must be disabled by pulling the FLTEN pin voltage lower than $V_{IL(FLTEN)}$. Otherwise, the PT16978 detects an open-circuit fault or single LED short-circuit fault and reports a fault on the FAULT pin. The FLTEN pin is used to avoid false diagnostics due to low supply voltage.

5.13.8 OVER-TEMPERATURE PROTECTION

The PT16978 monitors device junction temperature. When the junction temperature reaches thermal shutdown threshold $T_{(TSD)}$, the output shuts down. Once the junction temperature falls below $T_{(TSD)}$ - $T_{(TSD\_HYS)}$, the device recovers to normal operation. During over-temperature protection, the FAULT pin is pulled low.

5.14 FAULT BUS OUTPUT WITH ONE-FAILS–ALL-FAIL

During normal operation, The FAULT pin of PT16978 is weakly pulled up by an internal pull-up current source, $I_{(FAULT\_pullup)}$. If any fault scenario occurs, the FAULT pin is strongly pulled low by the internal pull-down current sink, $I_{(FAULT\_pulldown)}$ to report out the fault alarm.

Meanwhile, the PT16978 also monitors the FAULT pin voltage internally. If the FAULT pin is pulled low by external current sink below $V_{IL(FAULT)}$, the current output is turned off even though there is no fault detected on owned outputs. The device does not resume to normal operation until the FAULT pin voltage rises above $V_{IH(FAULT)}$.

Based on this feature, the PT16978 is able to construct a FAULT bus by tying FAULT pins from multiple devices to achieve one-fails-all-fail function as Figure 12 showing. The lower side PT16978 (B) detects any kind of LED fault and pulls low the FAULT pin. The low voltage on FAULT pin is detected by upper side PT16978 (A) because the FAULT pins are connected of two devices. The upper side PT16978 (A) turns off all output current for each channel as a result. If the FAULT pins of each PT16978 are all connected to drive the base of an external PNP transistor as illustrated in Figure 13, the one-fails–all-fail function is disabled and only the faulty channel is turned off.

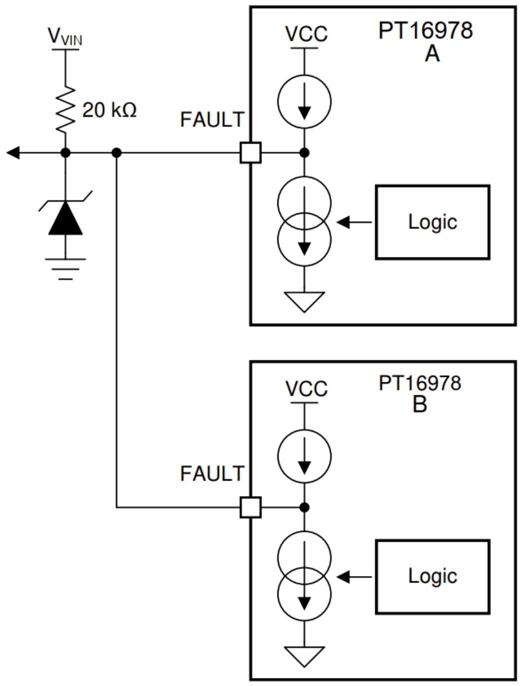


Figure 12 FAULT Bus for One-Fails-All-Fail Application

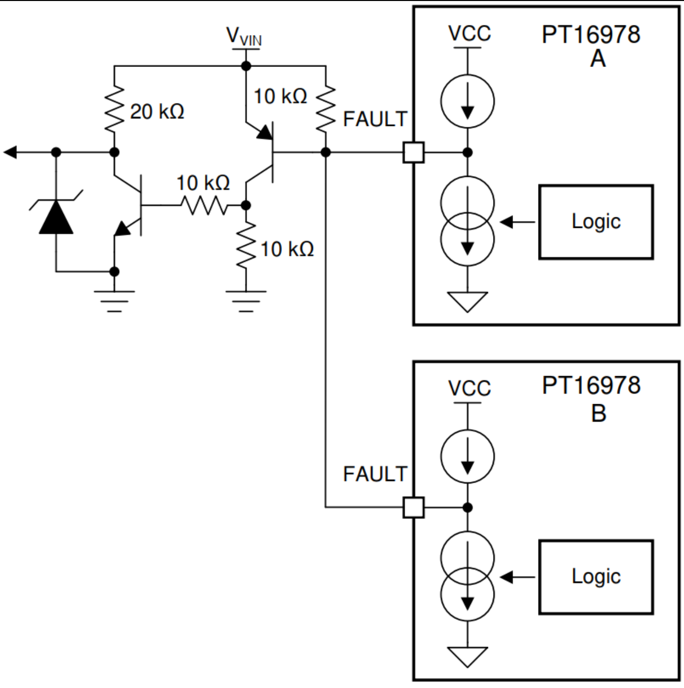


Figure 13 FAULT Bus for One-Fails-Others-On Application

5.15 FAULT TABLE

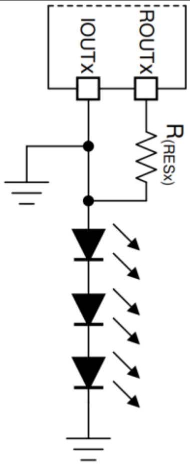
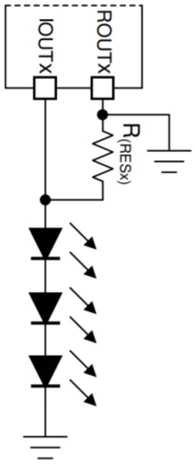
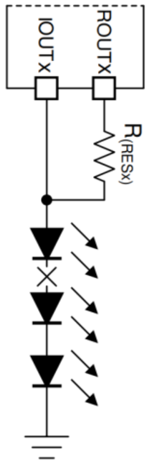
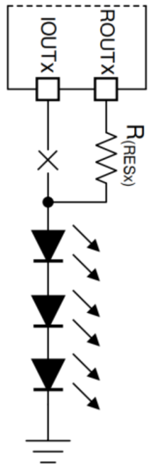
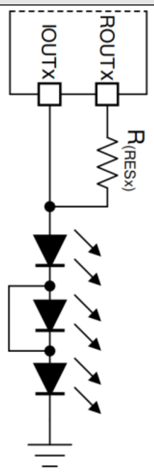
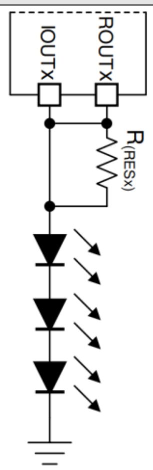
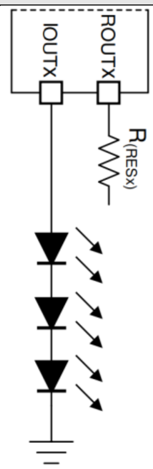
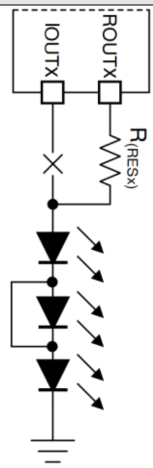
Table 1 FLTEN = HIGH

Fault status	Fault Type	Detection Mechanism	Control Input	Deglitch Time	Fault Action	Fault Handling Routine	Fault Recover
FAULT=H	IREF short to GND	$V_{(IREF)} < V_{(IREF\_SHORT\_th)}$	EN=H	$t_{(IREF\_deg)}$	Constant current pulldown	Device turns all output off. IREF current clamps to $I_{(IREF\_ST\_Clamp)}$. IADJ current output is turned off	Auto recovery
	IREF open	$I_{(IREF)} < I_{(IREF\_OPEN\_th)}$	EN=H	$t_{(IREF\_deg)}$	Constant current pulldown	Device turns all output off. IADJ current are turned off too.	Auto recovery
	SLS_SET short to GND	No detection	EN=H	N/A	No Action	$V_{(SLS\_th\_falling)} = 0$ V	Auto recovery
	SLS_SET open	No detection	EN=H	N/A	No Action	Disable single-LED Short circuit detection.	Auto recovery
	IADJ short to GND	No detection	EN=H	N/A	No Action	$V_{(CS\_REG)} = 50$ mV	Auto recovery
	IADJ open	No detection	EN=H	N/A	No Action	$V_{(CS\_REG)} = 400$ mV	Auto recovery
	Open circuit or Short to supply	$V_{(VIN)} - V_{(IOUT)} < V_{(OPEN\_th\_rising)}$	EN = H & PWMx = H	$t_{(OPEN\_deg)}$	Constant current pulldown	Device turns failed output off and retries with constant current $I_{(retry)}$, ignoring the PWM input.	Auto recovery
	Short to GND	$V_{(IOUT)} < V_{(SG\_th\_falling)}$ OR $V_{(ROUT)} < V_{(SG\_th\_falling)}$	EN = H & PWMx = H	$t_{(SG\_deg)}$	Constant current pulldown	Device turns failed output off and retries with constant current $I_{(retry)}$, ignoring the PWM input.	Auto recovery
	Single LED short circuit	$V_{(VIN)} - V_{(IOUT)} > V_{(OPEN\_th\_falling)}$ & $V_{(SG\_th\_falling)} < V_{(IOUT)} < V_{(SLS\_th\_falling)}$	EN = H & PWMx = H	$t_{(SLS\_deg)}$	Constant current pulldown	Device turns failed output off and retries every 10 ms by turning output on for 300 µs when PWM input is logic high.	Auto recovery
	Over temperature	$T_J > T_{(TSD)}$	EN=H	$t_{(TSD\_deg)}$	Constant current pulldown	Device turns all output channels off, SLS-SET and IADJ off.	Auto recovery
FAULT=L	Fault is detected	Device turns off remained channels in operation.					
	No fault is detected	Device turns all output channels off, IREF, SLS_SET and IADJ off.					

Table 2 FLTEN = LOW

Fault status	Fault Type	Detection Mechanism	Control Input	Deglitch Time	Fault Action	Fault Handling Routine	Fault Recover
FAULT=H	IREF short to GND	$V_{(IREF)} < V_{(IREF\_SHORT\_th)}$	EN=H	$t_{(IREF\_deg)}$	Constant current pulldown	Device turns all output off. IREF current clamps to $I_{(IREF\_ST\_Clamp)}$. IADJ current output is turned off	Auto recovery
	IREF open	$I_{(IREF)} < I_{(IREF\_OPEN\_th)}$	EN=H	$t_{(IREF\_deg)}$	Constant current pulldown	Device turns all output off. IADJ current are turned off too.	Auto recovery
	SLS_SET short to GND	No detection	EN=H	N/A	No Action	$V_{(SLS\_th\_falling)} = 0$ V	Auto recovery
	SLS_SET open	No detection	EN=H	N/A	No Action	Disable single-LED Short circuit detection.	Auto recovery
	IADJ short to GND	No detection	EN=H	N/A	No Action	$V_{(CS\_REG)} = 50$ mV	Auto recovery
	IADJ open	No detection	EN=H	N/A	No Action	$V_{(CS\_REG)} = 400$ mV	Auto recovery
	Open circuit or Short to supply	Ignored					
	Single LED short circuit						
	Short to GND	$V_{(IOUT)} < V_{(SG\_th\_falling)}$ OR $V_{(ROUT)} < V_{(SG\_th\_falling)}$	EN = H & PWMx = H	$t_{(SG\_deg)}$	Constant current pulldown	Device turns output off and retries with constant current $I_{(retry)}$, ignoring the PWM input.	Auto recovery
	Over temperature	$T_J > T_{(TSD)}$	EN=H	$t_{(TSD\_deg)}$	Constant current pulldown	Device turns all output channels off,SLS-SET and IADJ off.	Auto recovery
FAULT=L	Fault is detected	Device turns all output channels off and keeps retry on the failed channels.					
	No fault is detected	Device turns all output channels off, IREF, SLS_SET and IADJ off.					

5.16 LED FAULT SUMMARY

Case 1	Case 2	Case 3	Case 4
			
LED Short-to-GND Fault	LED Short-to-GND Fault	LED Open Fault	LED Open Fault
Case 5	**Case 6**	**Case 7**	**Case 8**
			
Single-LED-Short Fault	No Fault	No Fault	LED Open Fault

5.17 DEVICE FUNCTIONAL MODES

5.17.1 UNDERVOLTAGE LOCKOUT

When the device is in under voltage lockout status, the PT16978 disables all functions until the supply rises above the $V_{(POR\_rising)}$ threshold.

5.17.2 NORMAL OPERATION

The device drives an LED string in normal operation when VIN>5V. With enough voltage drop across VIN and OUT, the device is able to drive the output in constant-current mode.

5.17.3 LOW-VOLTAGE DROPOUT OPERATION

When the device drives an LED string in low-dropout operation, if the $V_{(dropout)}$ is less than the open-circuit detection threshold, the device may report a false open-circuit fault or single LED short-circuit fault. It recommends only enabling the open-circuit detection and single LED short-circuit detection when VIN voltage is enough higher than LED string voltage to avoid a false open-circuit detection.

5.17.4 FAULT MODE

When the device detects any fault, the device tries to pull down the FAULT pin with a constant current. If the FAULT bus is pulled down, the device switches to fault mode and consumes a fault current of $I_{(Fault)}$.

6 ABSOLUTE MAXIMUM RATINGS

	VOLTAGE	UNIT
VIN, EN, FLTEN, ISENx, PWMx, FAULT, IOUTx, ROUTx, IADJ	−0.3 to 45	V
SLS_SET, IREF	−0.3 to 5.5	V

* Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device.
* Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

7 ATTRIBUTES

ESD Ratings	
Human Body Model (HBM)	± 2000V
Charge Device Mode (CDM)	± 1000 V
ENVIRONMENT	
Operating ambient temperature, T_A	−40 to 125°C
Operating junction temperature, T_J	−40 to 150°C
Storage temperature, T_{STG}	−40 to 150°C
Moisture Sensitivity	MSL 3

8 RECOMMENDED OPERATING CONDITIONS

	MIN	MAX	UNIT
VIN	5	40	V
ISENx	$V_{(VIN)}$ - $V_{(CS\_REG)}$		V
EN, FLTEN, PWMx, FAULT, IOUTx, ROUTx	0	$V_{(VIN)}$	V
IADJ	0	2.75	V
SLS_SET	0	3.5	V
IREF	50	250	µA

9 THERMAL INFORMATION

			UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	41	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	36	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	19	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	6	°C/W

10 ELECTRICAL CHARACTERISTICS

($V_{(VIN)}$ = 14 V, T_J = –40°C to 150°C)

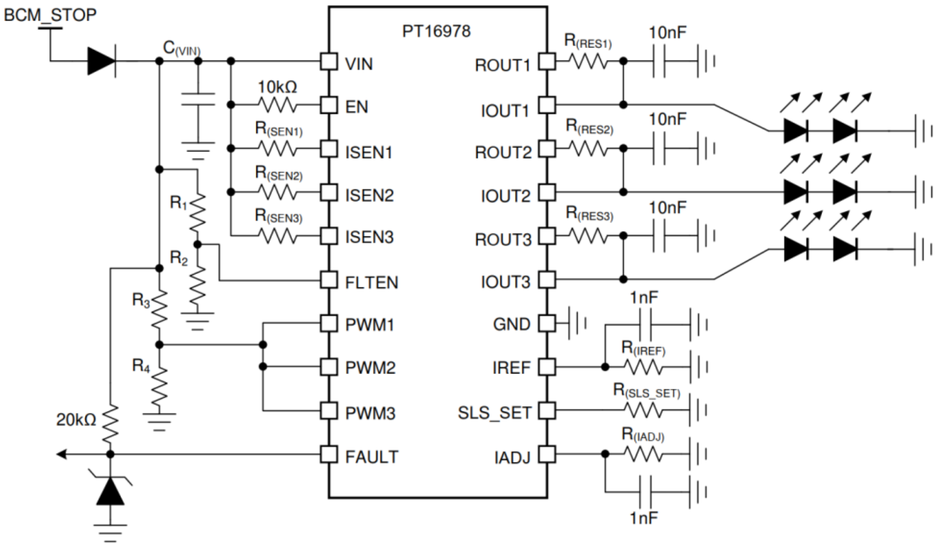
PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
BIAS						
$V_{(POR\_rising)}$	Supply voltage POR rising threshold		3.8	3.9	4.1	V
$V_{(POR\_falling)}$	Supply voltage POR falling threshold		3.4	3.6	3.7	V
$I_{(SD)}$	Device shutdown current	$V_{(EN)}$ = 0 V	10	15	20	µA
$I_{(Quiescent)}$	Device standby ground current	PWM = HIGH	1.6	1.9	2.4	mA
$I_{(Fault)}$	Device supply current in fault mode	PWM = HIGH, FAULT externally pulled LOW	0.3	0.45	0.7	mA
LOGIC INPUTS (EN, FLTEN, PWM)						
$V_{IL(EN)}$	Input logic-low voltage, EN				0.8	V
$V_{IH(EN)}$	Input logic-high voltage, EN		2.0			V
$I_{(EN\_pulldown)}$	EN pulldown current	$V_{(EN)}$ = 12 V	2.1	3.1	4.1	µA
$V_{IL(FLTEN)}$	Input logic-low voltage, FLTEN		1.045	1.1	1.155	V
$V_{IH(FLTEN)}$	Input logic-high voltage, FLTEN		1.14	1.2	1.26	V
$V_{IL(PWM)}$	Input logic-low voltage, PWM		1.045	1.1	1.155	V
$V_{IH(PWM)}$	Input logic-high voltage, PWM		1.14	1.2	1.26	V
CONSTANT-CURRENT DRIVER						
$I_{(OUTx\_Tot)}$	Device output-current for each channel	100% duty cycle	5		150	mA
$V_{(CS\_REG)}$	Sense-resistor regulation voltage	T_A = –40°C to +125°C, IADJ ground	46	50	54	mV
		T_A = –40°C to +125°C, $V_{(IADJ)}$ = 0.68 V	95	100	105	
		T_A = –40°C to +125°C, $V_{(IADJ)}$ = 1.365 V	192	200	208	
		T_A = –40°C to +125°C, $V_{(IADJ)}$ = 2.75 V	385	400	415	
$\Delta V_{(CS\_c2c)}$	Channel to channel mismatch	$\Delta V_{(CS\_c2c)} = 1 - V_{(CS\_REGx)}/V_{avg(CS\_REG)}$, $V_{(IADJ)}$ = 0.68 V	-3		+3	%
		$\Delta V_{(CS\_c2c)} = 1 - V_{(CS\_REGx)}/V_{avg(CS\_REG)}$, $V_{(IADJ)}$ = 1.365 V	-3		+3	
$\Delta V_{(CS\_d2d)}$	Device to device mismatch	$\Delta V_{(CS\_d2d)} = 1 - V_{avg(CS\_REG)}/V_{nom(CS\_REG)}$, $V_{(IADJ)}$ = 0.68 V	-4		+4	%
		$\Delta V_{(CS\_d2d)} = 1 - V_{avg(CS\_REG)}/V_{nom(CS\_REG)}$, $V_{(IADJ)}$ = 1.365 V	-4		+4	
$R_{(CS\_REG)}$	Sense-resistor range		0.65		20	Ω
$V_{(DROPOUT)}$	Voltage dropout from ISENx to IOUTx, ROUTx open	current setting of 100 mA		200	400	mV
		current setting of 150 mA		300	600	
	Voltage dropout from ISENx to ROUTx, IOUTx open	current setting of 100 mA		280	600	mV
		current setting of 150 mA		400	900	
$I_{(ROUTx)}$	Ratio of ROUTx current to total current	$I_{(ROUTx)}/I_{(OUTx\_Tot)}$, $V_{(ISENx)} - V_{(ROUTx)}$ > 1 V	95			%
$V_{(IREF)}$	IREF voltage		1.225	1.235	1.245	V
$N_{(IADJ)}$	IADJ current output ratio	$I_{(IADJ)}/I_{(IREF)}$	9.7	10	10.3	
$V_{(IADJ\_SAT)}$	IADJ saturated voltage	$V_{(CS\_REG)}$ = 400 mV	2.7	2.8	2.9	V
$V_{(CS\_SAT)}$	$V_{(VIN)} - V_{(ISEN)}$	$V_{(IADJ)}$ = 3 V	380	400	420	mV

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
DIAGNOSTICS						
$V_{(OPEN\_th\_rising)}$	LED open rising threshold, $V_{(IN)} – V_{(OUT)}$		250	400	500	mV
$V_{(OPEN\_th\_falling)}$	LED open falling threshold, $V_{(IN)} – V_{(OUT)}$		400	500	600	mV
$V_{(SG\_th\_rising)}$	Channel output short-to-ground rising threshold		1.14	1.2	1.26	V
$V_{(SG\_th\_falling)}$	Channel output short-to-ground falling threshold		0.855	0.9	0.945	V
$N_{(SLS\_SET)}$	SLS_SET current output ratio	$I_{(SLS\_SET)}/I_{(IREF)}$	0.98	1	1.02	
$N_{(OUT)}$	OUT voltage attenuation ratio	$V_{(OUT)}$ = 3 to 14 V.	3.9	4	4.1	
$I_{(Retry)}$	Channel output $V_{(IOUT)}$ short to ground retry current		0.6	0.9	1.3	mA
$I_{(IREF\_OPEN\_th)}$	IREF open threshold		8	10	12	µA
$V_{(IREF\_SHORT\_th)}$	IREF short-to-ground threshold		0.5	0.6	0.7	V
$I_{(IREF\_ST\_Clamp)}$	Current clamp for IREF short-to-GND		300	380	460	µA
FAULT						
$V_{IL(FAULT)}$	Logic input low threshold				0.7	V
$V_{IH(FAULT)}$	Logic input high threshold		2.0			V
$t_{(FAULT\_rising)}$	Fault detection rising edge deglitch time			25		µs
$t_{(FAULT\_falling)}$	Fault detection falling edge deglitch time			0.1		µs
$I_{(FAULT\_pulldown)}$	FAULT internal pull-down current	$V_{(FAULT)}$ = 0.7 V	1.5	2	2.5	mA
$I_{(FAULT\_pullup)}$	FAULT internal pull-up current		4	9	14	µA
$I_{(FAULT\_leakage)}$	FAULT leakage current	$V_{(FAULT)}$ = 40 V	0	1	2	µA
THERMAL PROTECTION						
$T_{(TSD)}$	Thermal shutdown junction temperature threshold		165	170	175	°C
$T_{(TSD\_HYS)}$	Thermal shutdown junction temperature hysteresis			15		°C
Timing Requirements						
$t_{(PWM\_delay\_rising)}$	PWM rising edge delay, $V_{IH(PWM)}$ voltage to 10% of output when $V_{(VIN)}$ = 12 V, $V_{(IOUT)}$ = 6 V, $V_{(CS\_REG)}$ = 100 mV, $R_{(ISENx)}$ = 0.665 Ω and $R_{(ROUTx)}$ = 56 Ω, t1 as shown in Figure 4			2.5		µs
	PWM rising edge delay, $V_{IH(PWM)}$ voltage to 10% of output when $V_{(VIN)}$ = 12 V, $V_{(IOUT)}$ = 6V, $V_{(CS\_REG)}$ = 50 mV, $R_{(ISENx)}$ = 0.665 Ω and $R_{(ROUTx)}$ = 56 Ω, t1 as shown in Figure 4			3		µs
$t_{(Current\_rising)}$	Output current rising from 10% to 90% when $V_{(VIN)}$= 12 V, $V_{(IOUT)}$ = 6 V, $V_{(CS\_REG)}$ = 100 mV, $R_{(ISENx)}$ = 0.665 Ω and $R_{(ROUTx)}$ = 56 Ω, t2 as shown in Figure 4			1.5		µs
	Output current rising from 10% to 90% when $V_{(VIN)}$ = 12 V, $V_{(IOUT)}$ = 6 V, $V_{(CS\_REG)}$ = 50 mV, $R_{(ISENx)}$ = 0.665 Ω and $R_{(ROUTx)}$ = 56 Ω, t2 as shown in Figure 4			2		µs
$t_{(PWM\_delay\_falling)}$	PWM falling edge delay, $V_{IL(PWM)}$ voltage to 90% of output current when $V_{(VIN)}$ = 12 V, $V_{(IOUT)}$ = 6 V, $V_{(CS\_REG)}$ = 100 mV, $R_{(ISENx)}$ = 0.665 Ω and $R_{(ROUTx)}$ = 56 Ω, t3 as shown in Figure 4			2		µs
	PWM falling edge delay, $V_{IL(PWM)}$ voltage to 90% of output current when $V_{(VIN)}$ = 12 V, $V_{(IOUT)}$ = 6 V, $V_{(CS\_REG)}$ = 50 mV, $R_{(ISENx)}$ = 0.665 Ω and $R_{(ROUTx)}$ = 56 Ω, t3 as shown in Figure 4			2		µs
$t_{(Current\_falling)}$	Output current falling from 90% to 10% when $V_{(VIN)}$ = 12 V, $V_{(IOUT)}$ = 6 V, $V_{(CS\_REG)}$= 100 mV, $R_{(ISENx)}$ = 0.665 Ω and $R_{(ROUTx)}$ = 56 Ω, t4 as shown in Figure 4			3.5		µs
	Output current falling from 90% to 10% when $V_{(VIN)}$= 12 V, $V_{(IOUT)}$ = 6 V, $V_{(CS\_REG)}$ = 50 mV, $R_{(ISENx)}$ = 0.665Ω and $R_{(ROUTx)}$ = 56 Ω, t4 as shown in Figure 4			1.2		µs
$t_{(STARTUP)}$	VIN rising edge to 10% output current when $C_{(IREF)}$ = $C_{(IADJ)}$= 10 pF, $V_{(IOUT)}$ = 6V, $V_{(CS\_REG)}$ = 100 mV, $R_{(ISENx)}$ = 0.665 Ω and $R_{(ROUTx)}$ = 56 Ω, t5 as shown in Figure 4			95		µs

TEST CONDITIONS		MIN	TYP	MAX	UNIT
Timing Requirements					
$t_{(IREF\_deg)}$	IREF pin open and short to GND detection deglitch time		125		µs
$t_{(OPEN\_deg)}$	LED-open fault-deglitch time, t_7 as shown in Figure 8		125		µs
$t_{(SG\_deg)}$	Output short-to-ground detection deglitch time, t_8 as shown in Figure 7		125		µs
$t_{(Recover\_deg)}$	Open and Short fault recovery deglitch time, t_{10} as shown in Figure 7 and Figure 8		125		µs
$t_{(SLS\_deg)}$	Single LED short-circuit detection deglitch time, t_9 as shown in Figure 10		135		µs
$t_{(SLS\_retry\_interval)}$	Single LED short-circuit failure retry interval time, t_{11} as shown in Figure 10		10000		µs
$t_{(SLS\_retry\_period)}$	Single LED short-circuit failure retry period time, t_{12} as shown in Figure 10		300		µs
$t_{(SLS\_retry\_deg)}$	Single LED short-circuit failure retry deglitch time, t_{13} as shown in Figure 10		50		µs
$t_{(FAULT\_recovery)}$	Fault recovery delay time, t_{14} as shown in Figure 7, Figure 8 and Figure 10		50		µs
$t_{(TSD\_deg)}$	Thermal over temperature deglitch time		50		µs

11 DESIGN GUIDE

11.1 APPLICATION CIRCUIT



11.2 DETAILED DESIGN PROCEDURE

STEP 1: Determine the reference current setting resistor, $R_{(IREF)}$, by using Equation 8.

$$I_{IREF} = \frac{V_{IREF}}{R_{IREF}} \tag{8}$$

- $V_{(IREF)}$ = 1.235 V (typical)
- $I_{(IREF)}$ = 100 µA (recommended)

STEP 2: Design the IADJ resistor, $R_{(IADJ)}$, for setting the regulation voltage, $V_{(CS\_REG)}$ by using Equation 9.

$$R_{IADJ} = \frac{V_{CS\_REG} \times 17}{I_{IREF} \times 25} \tag{9}$$

- $V_{(CS\_REG)}$ = 100 mV (recommended)
- $I_{(IREF)}$ = 100 µA (recommended)

It recommends 100 mV for reference voltage across current sensing resistor, $R_{(SENx)}$ if the IADJ pin is notused for driving off-board binning resistor or NTC resistor. The calculated result for $R_{(IADJ)}$ is 680 Ω when $V_{(CS\_REG)}$ = 100 mV.

STEP 3: Determine the current sensing resistor, $R_{(SENx)}$, by using Equation 10.

$$R_{SENx} = \frac{V_{IREF} \times R_{IADJ} \times 25}{R_{IREF} \times I_{INx} \times 17} \tag{10}$$

- $V_{(IREF)}$ = 1.235 V (typical)
- $R_{(IADJ)}$ = 680 Ω
- $R_{(IREF)}$ = 12.3 kΩ
- $I_{(INx)}$ = 150mA

According to design requirements, output current for each channel is same so that the R(SEN1) = R(SEN2) =R(SEN3) = 0.67 Ω.

STEP 4: Design the current distribution between $I_{(IOUTx)}$ and $I_{(ROUTx)}$, and calculate the current sharing resistor, $R_{(ROUTx)}$ by using Equation 11. The $R_{(ROUTx)}$ value actually decides the current distribution for $I_{(IOUTx)}$ path and $I_{(ROUTx)}$ path, basic principle is to design the $R_{(ROUTx)}$ to consume appropriate 50% total power dissipation at typical supply operating voltage.

$$R_{ROUTx} = \frac{V_{VIN} - V_{IOUTx}}{I_{INx} \times 0.5} \tag{11}$$

- $V_{(VIN)}$ = 12 V (typical)
- $I_{(INx)}$ = 150mA

The calculated result for $R_{(ROUTx)}$ resistor value including $R_{(ROUT1)}$, $R_{(ROUT2)}$ and $R_{(ROUT3)}$ is 80 Ω when $V_{(IOUTx)}$ is typical 2 × 3.0 V = 6.0 V.

STEP 5: Design the single-LED short-circuit threshold voltage and calculate the value of $R_{(SLS\_SET)}$ resistor for setting single-LED short-circuit threshold by using Equation 12.
The total forward voltage for two LEDs in serial is 2 × 3.0 V(typ) = 6.0 V. Once either of two LEDs is defective with short-circuit behavior, the total forward voltage for remaining one LED in serial is between 3.3 V (max) and 2.7 V (min). So the 3.6 V is selected to be threshold for single-LED short-circuit, $V_{(SLS\_th\_falling)}$.

$$R_{SLS\_SET} = \frac{R_{IREF} \times V_{\mathrm{SLS\_th\_falling}}}{V_{IREF} \times N_{SLS\_SET} \times N_{OUT}} \tag{12}$$

- $V_{(IREF)}$ = 1.235V (typical)
- $R_{(IREF)}$ = 12.3 kΩ
- $R_{(SLS\_SET)}$ is in kΩ unit
- $N_{(OUT)}$ = 4 (typical)
- $N_{(SLS\_SET)}$ =1 (typical)

The calculated result for $R_{(SLS\_SET)}$ is 8.96 kΩ for $V_{(SLS\_th\_falling)}$ is 3.6 V

STEP 6: Design the threshold voltage of VIN to enable the LED open-circuit and single-LED short-circuit diagnostics, and calculate voltage divider resistor value for R1 and R2 on FLTEN pin.
The maximum forward voltage of LED-string is 2 × 3.3 V = 6.6 V. To avoid the open-circuit fault or single-LED short-circuit reported in low-dropout operation conditions, additional headroom between VIN and IOUTx needs to be considered. The device must disable open-circuit detection and single-LED short circuit detection when the supply voltage is below LED-string maximum forward voltage plus $V_{(OPEN\_th\_rising)}$ and $V_{(CS\_REG)}$. The voltage divider resistor, R1 and R2 value can be calculated by Equation 13.

$$R_1 = \left(\frac{V_{(OPEN\_th\_rising)} + V_{(CS\_REG)} + V_{(IOUTx)}}{V_{IL(FLTEN)}} - 1 \right) \times R_2 \tag{13}$$

- $V_{(OPEN\_th\_rising)}$ = 500 mV (maximum)
- $V_{(CS\_REG)}$ = 100 mV
- $V_{IL(FLTEN)}$ = 1.045 V (minimum)
- R2 = 10 kΩ (recommended)

The calculated result for R1 is 58.9 kΩ when $V_{(IOUTx)}$ maximum voltage is 6.6 V and $V_{(CS\_REG)}$ is 100 mV.

STEP 7: Design the threshold voltage of VIN to turn on and off each channel of LED, and calculate voltage divider resistor value for R3 and R4 on PWM input pin.
The maximum forward voltage of LED-string is 2 × 3.3 V = 6.6 V. To make sure the current output on each of LED-string is normal, each LED-string needs to be turned off when VIN voltage is lower than LED minimum required forward voltage plus dropout voltage between ISENx to IOUTx and $V_{(CS\_REG)}$. The voltage divider resistor, R3 and R4 value can be calculated by Equation 14.

$$R_3 = \left(\frac{V_{(DROPOUT)} + V_{(CS\_REG)} + V_{(IOUTx)}}{V_{IH(PWM)}} - 1 \right) \times R_4 \tag{14}$$

- $V_{(DROPOUT)}$ = 300 mV (typical)
- $V_{(CS\_REG)}$ = 100 mV
- $V_{IH(PWM)}$ = 1.26 V (maximum)
- R4 = 10 kΩ (recommended)

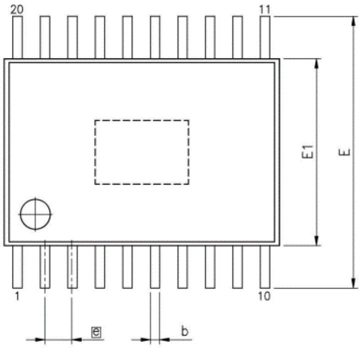
The calculated result for R3 is 45.56 kΩ when V(IOUTx) voltage is 6.6 V and $V_{(CS\_REG)}$ is 100 mV.

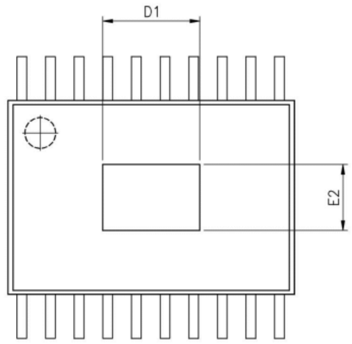
12 PCB LAYOUT

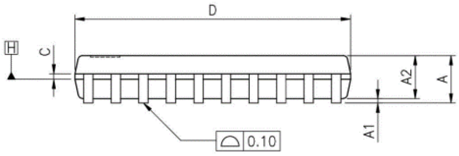
1. It recommends large thermal dissipation area in both top and bottom layers of PCB. The copper pouring area in same layer with PT16978 footprint should directly cover the thermal pad land of the device with wide connection as much as possible. The copper pouring in opposite PCB layer or inner layers should be connected to thermal pad directly through multiple thermal vias.
2. It recommends to place $R_{(ROUTx)}$ resistors away from the PT16978 device with more than 20 mm distance because $R_{(ROUTx)}$ resistors are dissipating some amount of the power as well as the PT16978.
3. It is better to place two heat source components apart to reduce the thermal accumulation concentrated at small PCB area. The large copper pouring area is also required surrounding the $R_{(ROUTx)}$ resistors for helping thermal dissipating.
4. The noise immunity is the secondary consideration for PT16978 layout.
5. It recommends to place the noise decoupling capacitors for VIN, IADJ and IREF pins as close as possible to the pins.
6. It recommends to place the $R_{(SENx)}$ resistor as close as possible to the ISENx pins with the shortest PCB track to VIN pin.

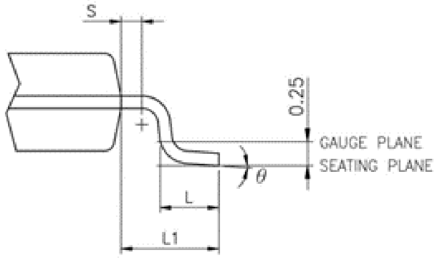
13 PACKAGE INFORMATION

HTSSOP20









Symbol	Dimensions		
	Min.	Nom.	Max.
A	—	—	1.20
A1	0.05	—	0.15
A2	0.80	1.00	1.05
b	0.19	—	0.30
c	0.09	—	0.20
e	0.65 BSC		
D	6.40	6.50	6.60
D1	—	3.99	—
E	6.40 BSC		
E1	4.30	4.40	4.50
E2	—	2.8	—
S	0.2	—	—
L	0.5	0.60	0.75
L1	1.00 REF		
θ	0°	—	8°

Note: 1. Refer to JEDEC MO-153 ACT
2. Unit: millimeter

IMPORTANT NOTICE

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